OPERATING AND SERVICE MANUAL

STANDING WAVE INDICATOR

415B

HEWLETT hp PACKARD

HP 415B

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The Hewlett-Packard Company certifies that this instrument was thoroughly tested and inspected and found to meet its published specifications when it was shipped from the factory. The Hewlett-Packard Company further certifies that its calibration measurements are traceable to the U.S. National Bureau of Standards to the extent allowed by the Bureau's calibration facility.

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OPERATING AND SERVICE MANUAL

MODEL 415B
STANDING WAVE INDICATOR

SERIALS PREFIXED: 970

(For other serials
see appendix)

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1501 PAGE MILL ROAD, PALO ALTO, CALIFORNIA, U.S.A.

Manual Part No. 00415-90017
Microfiche Part No. 00415-90018

Printed: July 1971

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Figure 1-1. Model 415B Standing Wave Indicator

Table 1-1. Specifications

Frequency:
1000 cps ±2%. Other frequencies 315 to 2020 cps available on special order. Should not be harmonically related to power line frequency.

Sensitivity:
0.1 μvolt (200-ohm input) for full scale deflection.

Noise Level:
At least 5 db below full scale when operated from a 200-ohm resistor at room temperature.

Bandwidth: 30 cps (nominal).

Calibration:
Square law. Meter reads swr, db.

Range:
70 db. Input attenuator provides 60 db in 10 db steps. Accuracy ±0.1 db per 10 db step. Maximum cumulative error ±0.2 db.

Scale Selector:
"Normal", "Expand", and "-5 db".

Meter Scales:
SWR 1-4, swr 3-10, expanded swr 1-1.3, db 0-10, expanded db 0-2.

Gain Control:
Adjusts to convenient reference level. Range at least 10 db.

Input:
"Bolo" (200 ohms). Bias provided for 8.7 ma bolometer or 1/100 amp fuse; or 4.3 ma low current bolometer.
"Crystal". 200 ohms for crystal rectifier.
"200,000 ohms". High impedance for crystal rectifier as null detector.

Recorder Output:
Jack provided for recording milliammeter having 1 ma full scale deflection, internal resistance of 1500 ohms or less.

Input Connector: BNC

Power:
115/230 volts ±10%, 50-60 cps, 55 watts. Other frequencies on special order.

SECTION I
GENERAL INFORMATION

1-1 GENERAL DESCRIPTION

The Model 415B Standing Wave Indicator is a high-gain, tuned electronic voltmeter operating at a fixed audio frequency. It is designed primarily for use in making standing-wave measurements in conjunction with a suitable detector and slotted line or waveguide section. The Model 415B may also be used as a null indicator in bridge circuits and other applications requiring a sensitive fixed-frequency indicator. It is calibrated to indicate directly in SWR or in db when used with square-law devices such as crystal diodes (at low signal levels) and barretters. The Model 415B also has expanded scales for accurate reading of small increments.

Operating frequency of the Model 415B is determined by a single plug-in filter. The instrument is normally supplied for operation at 1000 cps +2%. The operating frequency may be changed in the field by installing a new plug-in filter tuned to the desired frequency. Plug-in filters for any single frequency between 315 and 2020 cps are available from the Hewlett-Packard Company; the frequency selected should not be harmonically related to the power line frequency.

1-2 INITIAL INSPECTION

After the instrument is unpacked, it should be inspected carefully for damage received in transit. If any shipping damage is found, refer to the "Claim for Damage in Shipment" page in this manual.

1-3 POWER CABLE

The three-conductor power cable supplied with this instrument is terminated in a polarized three-prong male connector recommended by the National Electrical Manufacturers' Association (NEMA). The third contact is an offset round pin which grounds the instrument chassis when used with an appropriate receptacle. To use this NEMA connector in a two-contact receptacle, a three-prong to two-prong adapter should be used. When the adapter is used, the round pin is terminated in a short green lead from the adapter which can then be connected to a suitable ground.

1-4 230-VOLT OPERATION

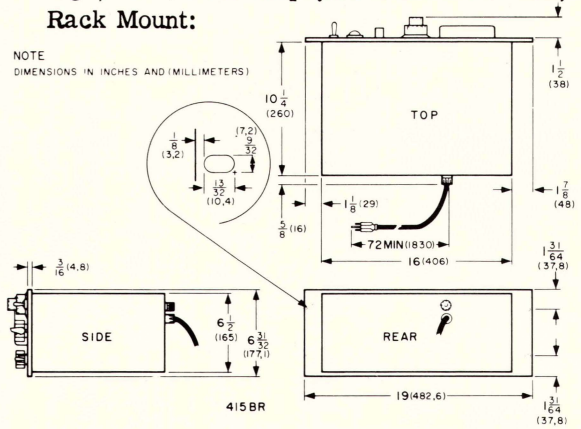
This instrument is shipped for 115 volt operation unless otherwise specified. For operation from a 230-volt source, turn the instrument off, change switch S6 on the rear panel to 230, and replace the fuse with the fuse listed for 230 volt operation in the Table of Replaceable Parts (Section V).

Table 1-1. Specifications (cont'd)

Dimensions:

Cabinet Mount: 7-1/2 in. wide, 11-3/4 in. high, 12-1/2 in. deep. (191 x 299 x 318 mm)

Rack Mount:



Net Weight:

Cabinet Mount: Net 13 lbs., (5,9 kg)

Rack Mount: Net 17 lbs., (7,7 kg)

Accessories Furnished:

415B-16E Cable Assembly

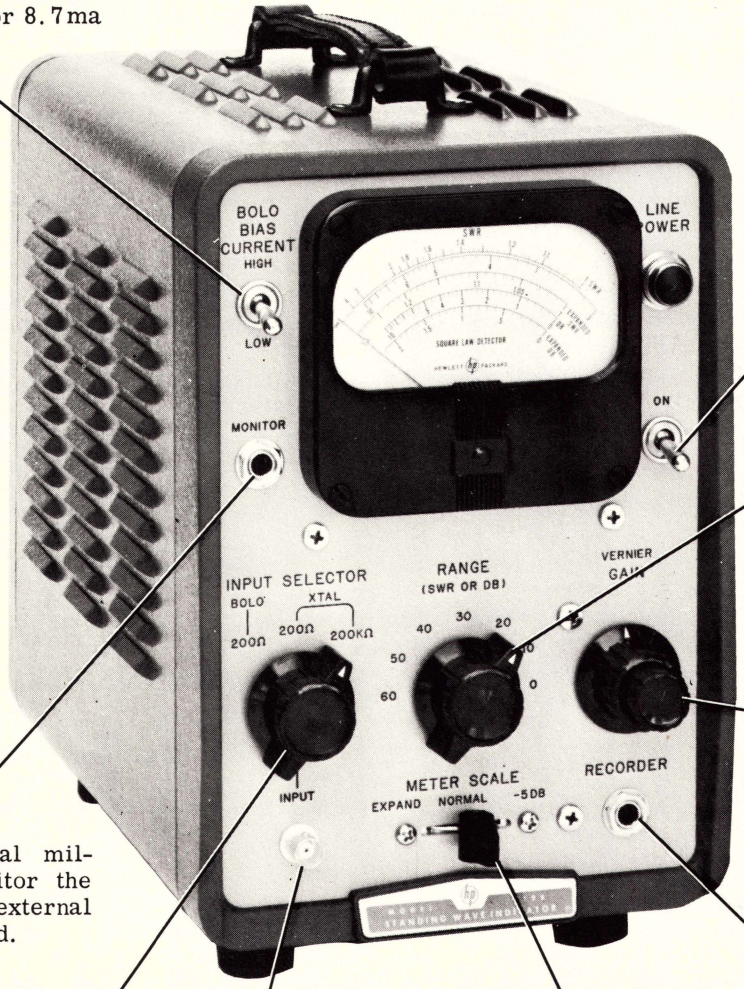
Accessories Available:

415B-42B Plug-in Filter 315-700 cps

415B-42C Plug-in Filter 700-2020 cps

10503A Video Cable Assembly, 4 feet of RG-58/U 50-ohm coaxial cable terminated at each end with UG-88/U Type BNC male connectors.

10501A Cable Assembly, 44 inches of RG-58/U 50-ohm coaxial cable terminated at one end only with UG-88/U Type BNC male connectors.



Select bolometer bias current of either 4.3 or 8.7ma

Power switch

Select meter sensitivity for the signal level being indicated.

Adjust meter for reading on expanded scales, normal scales, or shift meter downscale by 5 decibels.

Connect an external milliammeter to monitor the bias applied to an external barretter, if desired.

Select appropriate input for the type detector to be used.

Provides signal current corresponding to meter indication. Requires external 1500-ohm load for use.

Connect signal from detector or other signal source.

Adjust meter reading to full scale or other convenient reading.

Figure 2-1. Front Panel Controls and Terminals

SECTION II
OPERATING INSTRUCTIONS

2-1 CONTROLS AND TERMINALS

Refer to Figure 2-1 for explanation of the panel controls and terminals.

2-2 AUXILIARY EQUIPMENT REQUIRED

A typical test set up for making SWR measurements is shown in Figure 2-2. The auxiliary equipment required with the Model 415B follows:

A. SIGNAL SOURCE

The signal source should cover the desired frequency range and be amplitude modulated at the operating frequency of the Model 415B. Generally, squarewave modulation is used which reduces to a minimum the effects of harmonics and frequency modulation. If the signal source is pulse-modulated, the duty cycle should be not less than approximately 40%. Short pulse type signals or poor quality square waves can introduce measurement errors in the Model 415B.

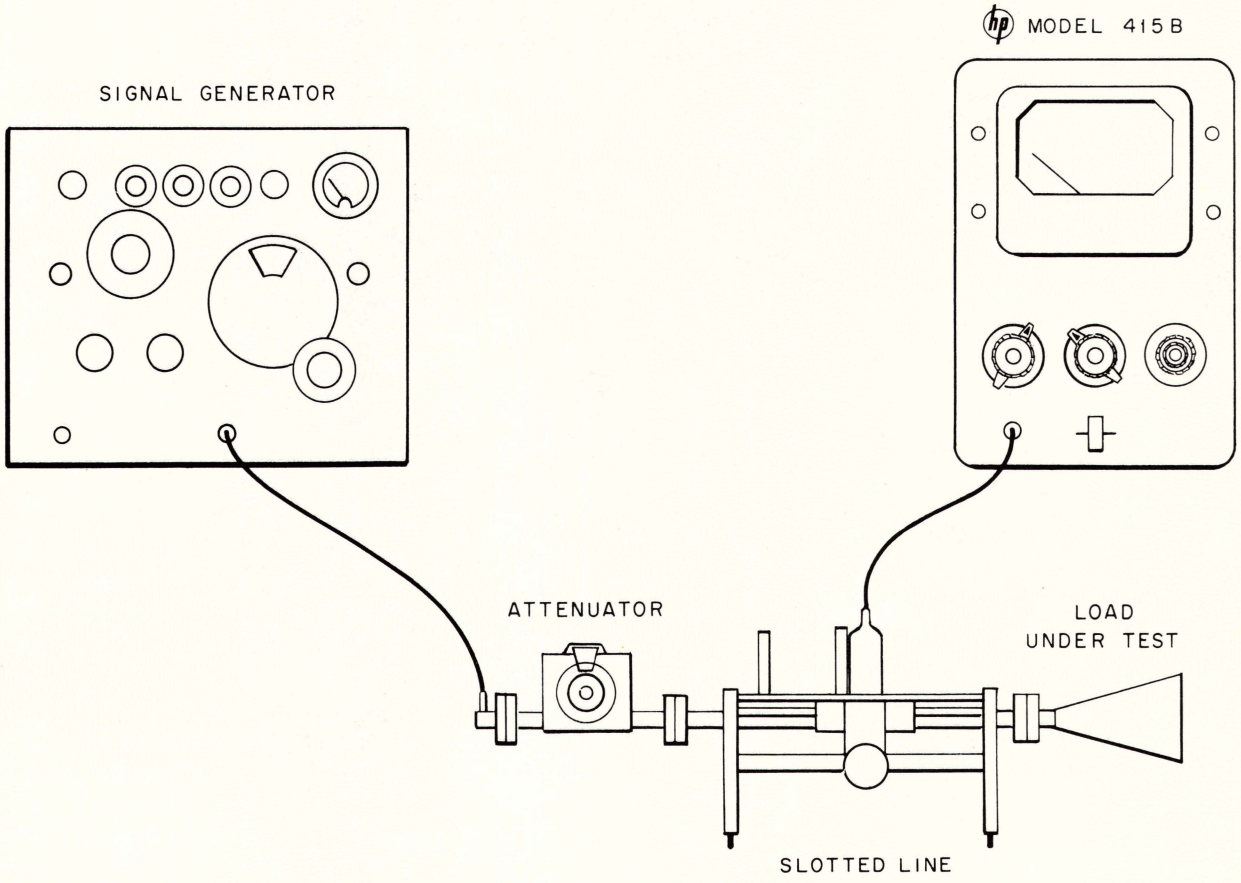


Figure 2-2. Test Setup

In many applications, it is necessary to minimize interaction between the oscillator and the load. In these cases, an isolating device should be used. For flexible and versatile operation, the signal source should indicate power output and should include an accurately calibrated attenuator.

B. CABLES OR WAVEGUIDES

The cable or waveguide used for connecting the source to a slotted section should match the source impedance over the desired frequency range.

C. SLOTTED SECTION

The slotted section should cover the desired frequency and be equipped with an accurate scale or indicator.

D. DETECTOR

The detector should be a square-law (output proportional to rf power input) device such as a barretter or a crystal diode operated at low signal levels. A barretter is reasonably square-law when used at low signal levels, but in general, this can not be said in all cases with crystal diodes. However, the sensitivity of crystals is considerably better than with barretters so that crystals are widely used as detectors for SWR measurements. See paragraph 2-5 when using crystal diode as detector.

E. KNOWN LOADS

Various terminations are required(i.e., a fixed and a movable short circuit) to establish reference points and to aid in calibrating the test set up.

2-3 TECHNIQUES IN SWR MEASUREMENTS

Basically, the measurement of a standing-wave ratio consists of setting the probe carriage at a voltage maximum position and setting the gain of the Model 415B to obtain a reading of 1.0. The probe carriage is then moved along the slotted line to a voltage minimum and the SWR is indicated directly on the scale of the Model 415B. This method, while straightforward and simple, may lead to serious errors under certain conditions. Paragraphs 2-4 through 2-9 discuss these errors and suggest techniques for minimizing their effects. In many cases only a knowledge of the SWR is required, but there are other cases, chiefly in design and development, where complete knowledge of the terminating equipment is desired. This can be obtained by measuring SWR and phase in the standing-wave pattern.

Generally, the impedance characteristic of the load is obtained by measuring the position of the voltage minimum. This position is compared to a shifted position of the voltage minimum which occurs when a known load replaces the load under test at a reference point on the slotted line. For convenience, the known load is usually a short circuit or shorting plate and the reference point is the load connection. The distance between these two minima is entered on a Smith Chart and the reactive component is determined. Detailed instructions for measuring the impedance characteristics of the load are given in paragraphs 2-10 through 2-13.

2-4 DETECTOR PROBE PENETRATION

A general rule in slotted line work is that the penetration of a sampling probe into the line should be held to a minimum. One of the major sources of error in SWR measurements is the failure to observe this rule.

The power extracted by the sampling probe causes distortion in the standing-wave pattern. This effect usually becomes greater as probe penetration is increased and can be explained by considering the probe as an admittance shunting the line.

Impedance in the standing-wave pattern varies along the line from maximum at a voltage maximum to a minimum at a voltage minimum. The shunt admittance introduced by the probe lowers these impedances, thus causing the measured SWR to be lower than the true SWR and shifting both the maxima and minima from their natural positions. The shift will be greater at a voltage maximum than at a voltage minimum.

Besides absorbing power and affecting the standing-wave pattern, the probe will also cause reflections in the line. These reflections will travel towards the signal source. If the signal source is not matched, these reflections are re-reflected toward the load and will cause additional errors in low SWR measurements.

An exception to the minimum penetration rule occurs when it is desired to examine in detail a voltage minimum in high SWR measurement. For this work, greater probe penetration can be tolerated because the voltage minimum corresponds to a low impedance point in the line. However, only at a voltage minimum can you tolerate substantial probe penetration.

2-5 PRECAUTIONS WHEN USING CRYSTAL DETECTORS

Whenever a crystal detector with a matched load resistor is used, the INPUT SELECTOR switch must be set at the XTAL-200KΩ position to obtain accurate square-law response. With an unloaded crystal, select the input impedance which gives maximum sensitivity. Usually the XTAL-200Ω position will give the best sensitivity. However, some crystal diodes may give higher output in the XTAL-200K Ω position. Maximum sensitivity is desirable so probe penetration in the slotted line can be kept to a minimum.

There are precautions to be observed concerning all crystal detector elements. Crystal diodes exhibit a departure from the ideal square-law response for which the 415B is calibrated. This departure tends to occur when the rf power level exceeds a few microwatts. This corresponds to a reading of approximately fullscale on the 30-db range of the 415B with the gain controls set to maximum. In paragraph 2-7, methods of calibrating the detector are discussed.

2-6 OPERATING PROCEDURES

The operating procedures for the Model 415B Standing Wave Indicator are divided into two classifications (A) low SWR (10 and below) and (B) high SWR measurements. The step-by-step procedure for making these measurements follows:

Both MONITOR and RECORDER jacks on the front panel of the Model 415B receive the three-terminal 1/4 inch diameter "tip-ring-sleeve" phone plug supplied with the instrument. Do not use the standard single-circuit phone plug in these jacks. In both jacks the sleeve connection is grounded to the instrument chassis and is not used as part of the output circuit; the ring and tip provide the connections to the appropriate signal circuit and must not be grounded externally.

A. LOW SWR MEASUREMENTS (10 and below)

1) Turn instrument ON. For maximum stability allow approximately 10 minutes warm-up.

2) Set INPUT SELECTOR switch for the type of detector that is to be used.

3) Connect the detector cable to the INPUT.

4) Set GAIN and VERNIER controls to approximately 3/4 maximum.

5) Set RANGE switch on 30-db or 40-db position. Adjust probe penetration to obtain up-scale reading.

6) Peak the meter by adjusting the modulation frequency of the signal source, if adjustable. Reduce probe penetration to keep meter on scale.

7) Peak the meter by tuning the probe detector, if tunable. Reduce probe penetration to keep meter on scale.

8) Peak the meter by moving the probe carriage along the line. Reduce probe penetration to keep meter on scale.

9) Adjust GAIN controls and/or output power from the signal source to obtain exactly full-scale reading.

10) Move the probe carriage along the line to obtain a minimum reading. Do not retune probe or detector circuit.

11) Read SWR, which is indicated directly on the 415B. The following examples refer to Figure 2-3.

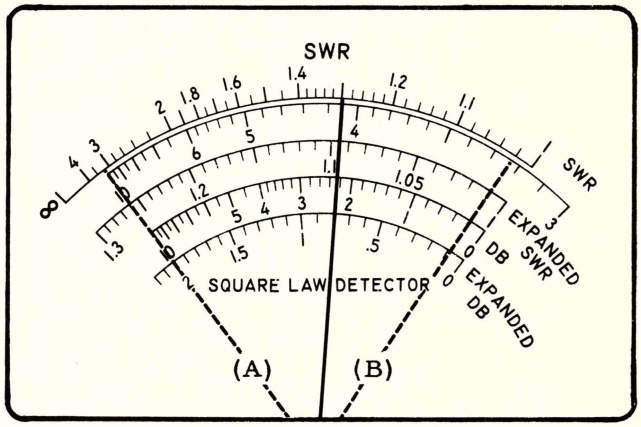


Figure 2-3. Detail of Meter Face

a. If the reading at the minimum is lower than 3 on the top scale (dashed pointer line A in Figure 2-3), set RANGE switch to next (40-db or 50-db) range and read the indication on the second SWR (3 to 10) scale. In Figure 2-3, the reading is 3.25 (dashed pointer line B).

b. If the RANGE switch is changed by two steps, use the top SWR scale; however, all indications on this scale must be multiplied by 10.

c. If the SWR is 1.3 or less, it can be read on the EXPANDED SWR or EXPANDED DB scale after the METER SCALE switch is set to EXPAND and steps 8, 9, 10 and 11 are repeated. In the EXPANDED position, set RANGE switch to next (40-db or 50-db) range and readjust GAIN control to obtain a reading of full-scale at the voltage maximum.

d. The standing-wave ratio may also be expressed in decibels using the DB and EXPANDED DB scales. If the SWR is between 5 and 10 on the DB scale, set METER SCALE switch to -5DB and set RANGE switch to next lower (CCW) range. To obtain a true reading, subtract 5 db from the indication on the DB scale.

A graph of SWR in decibels vs. voltage standing-wave ratio is shown in Figure 2-4.

For accurate measurements, it is good practice to take several readings with different amounts of probe penetration to detect any probe loading error in the standing-wave pattern.

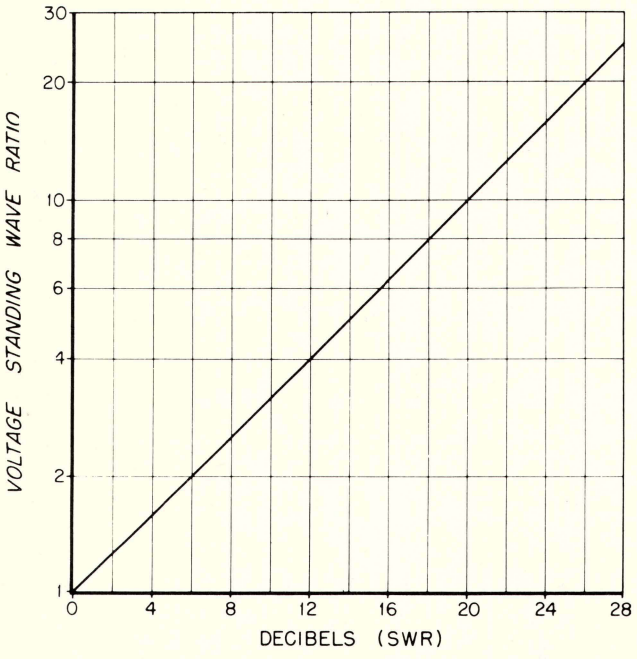


Figure 2-4. Graph Showing Standing Wave Ratio in DB vs. SWR

B. HIGH SWR MEASUREMENTS (above 10)

The straightforward measurement of SWR with conventional methods is generally applicable when measuring nominal SWR's up to 10, but at higher SWR's special techniques are desirable.

When the SWR is high, probe coupling must be increased if a reading is to be obtained at the voltage minimum. However, at the voltage maximum this high coupling may result in a deformation of the pattern, with consequent error in reading. In addition to this error caused by probe loading, there is also danger of error resulting from the change in detector characteristics at higher rf levels.

C. DOUBLE MINIMUM METHOD

In the double minimum method, it is necessary to establish the electrical distance between the points where the output is double the minimum (see Figure 2-5).

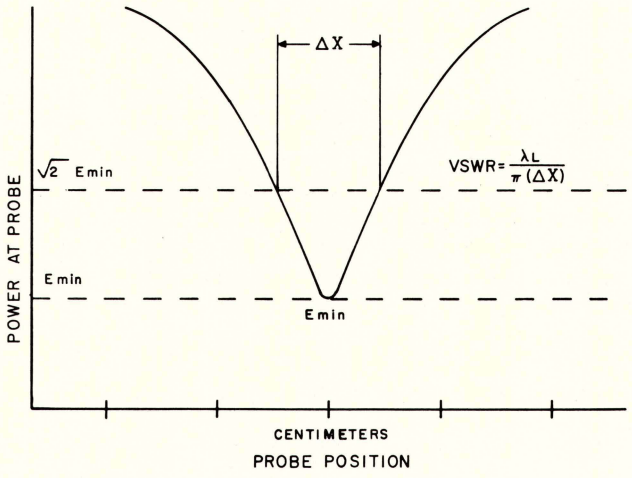


Figure 2-5. Graph Showing Double Minimum Method for Computing SWR

1) Repeat steps 1 through 7 in the Low SWR Measurement procedure.

2) Move the probe carriage along the line to obtain a minimum reading and note the probe carriage position.

3) For reference, adjust gain controls to obtain a reading of 3.0 on the DB scale. If a linear detector is being used, adjust GAIN controls for an indication of 1.5 on the DB scale.

4) Move the probe carriage along the line to obtain a reading of full-scale ("0") on the DB scale on each side of the minimum.

5) Record as d_1 and d_2, the probe carriage positions at the two equal readings obtained in step 4.

6) Short the line and measure the distance between successive minima. Twice this distance is λ_L, the guide wavelength.

The SWR can then be obtained by substituting this distance into the expression:

$$SWR = \frac{\lambda L}{\pi (d_1 - d_2)} = \frac{\lambda L}{\pi (\Delta X)}$$

Where λ_L is the guide wavelength; d_1 and d_2 are the locations of the twice-minimum points.

This method overcomes the effect of probe loading since the probe is always set around a voltage minimum where larger probe loading can be tolerated. However, it does not overcome the effect of detector characteristics.

D. CALIBRATED ATTENUATOR METHOD

Another method for measuring high SWR's is to use a calibrated variable rf attenuator between the signal source and the slotted line. Adjust the rf attenuator to keep the rectified output of the crystal diode equal at the voltage minimum and voltage maximum points. The SWR in db is the difference in the attenuator settings.

1) Repeat steps 1 through 7 in Low SWR Measurements procedure.

2) Move the probe carriage along the line for a voltage minimum, adjust the rf attenuator to give a convenient indication on the meter, and note the rf attenuator setting.

3) Move the probe carriage along the line to a voltage maximum, adjust the rf attenuator to obtain the same indication on the meter as established in step 2, and note the rf attenuator setting.

4) The SWR may be read directly (in db) as the difference between the first and second readings.

While this method overcomes the effect of detector variations from a square-law characteristic, the effect of probe loading still remains. Be careful; always use minimum probe penetration.

2-7 CHECKING OF SQUARE-LAW RESPONSE

The square-law response of either a crystal diode or bolometer is easily checked with slotted line equipment.

A simple method of calibrating a detector is by increasing the power level in the slotted line in known steps and noting the detector response on the Model 415B.

Another method for calibrating a detector is to use a load having unity reflection coefficient (usually a short circuit). This load will then set up an electric field between adjacent minima in the slotted line closely approximating half a sine wave, thus giving a relative voltage that is a known function of the probe carriage position. *

Any new crystal being used for the first time should be checked, as there is often a significant variation between crystals. Data should be taken in both XTAL positions on the Model 415B, so that the better setting may be determined for any individual crystal diode.

2-8 LOCATION OF VOLTAGE MAXIMUM OR VOLTAGE MINIMUM

From the discussion on probe loading it has shown that it is more desirable to locate the voltage minimum than the voltage maximum since the effect of probe loading is less at the minimum. However, the location of a voltage minimum by a single measurement, particularly on low SWR, is usually inaccurate because of its broadness, thus making the true minimum position hard to determine. An accurate method of locating the voltage minimum is to obtain the position of the probe carriage at two equal output readings on either side of the minimum and then averaging these two readings.

2-9 PRECAUTIONS WITH SIGNAL SOURCES

Signal sources can introduce at least three undesirable characteristics that will affect slotted line measurements. These include presence of rf harmonics, frequency modulation, and spurious signals. Signal sources used for standing wave measurements should have relatively low harmonic content in their output. The standing wave ratio

*Ginzton, Edward L, "Microwave Measurements", pp. 142-144, McGraw-Hill Book Company, Inc., New York, N.Y. 1957

at a harmonic frequency may be considerably higher than at the fundamental. Spurious frequencies in the signal source are also undesirable, for, unless very slight, they will obscure the minimum points at high SWR values. Figure 2-6 shows plot of an SWR pattern made with signal source producing unwanted fm.

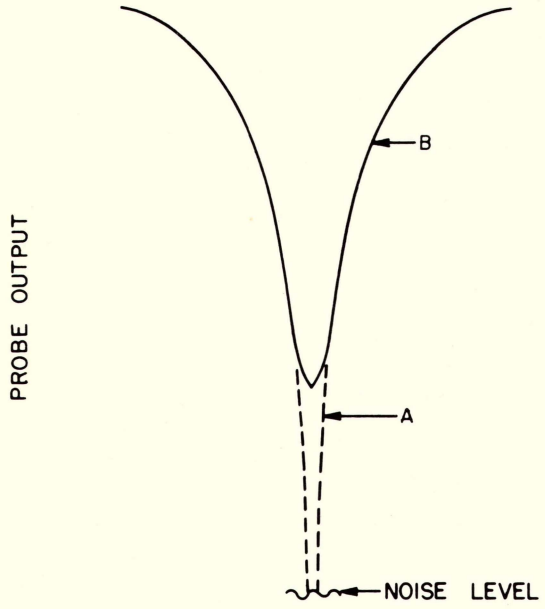


Figure 2-6. High Standing Wave Ratio Pattern
(A) Free of FM
(B) With Moderate FM

Instances are common where the presence of rf harmonics has led to very serious errors in SWR measurements. Such harmonics are usually present to an excessive degree only in signal sources that have coaxial outputs. Coaxial pickups of a broad-band type will often pass harmonic frequencies with greater efficiency than the fundamental. In waveguide systems, signal sources such as internal cavity klystrons have a more or less fixed coupling and in addition do not have pickups extending into the tuned cavity to cause perturbations of the cavity fields. Consequently, the harmonic problem is generally limited to coaxial systems. Harmonics become especially troublesome when the reflection coefficient of a load at a harmonic frequency is much larger than at the fundamental frequency--a common condition. When the harmonic content of the signal source is high, the large reflection coefficient of the load at the harmonic frequency can cause the harmonic standing wave fields to be of the same order of magnitude as the fields at the fundamental frequency. Thus, a device having a SWR of 2.0 at the fundamental frequency will often have a SWR of 20 or more at the second harmonic frequency. If such a device is driven from a signal source having, say, 15% second harmonic content, the peaks of the standing waves of second harmonic will be about one-fourth the amplitude of the peaks at the fundamental frequency. Figure 2-7 shows a typical SWR pattern obtained when the rf signal contains harmonics.

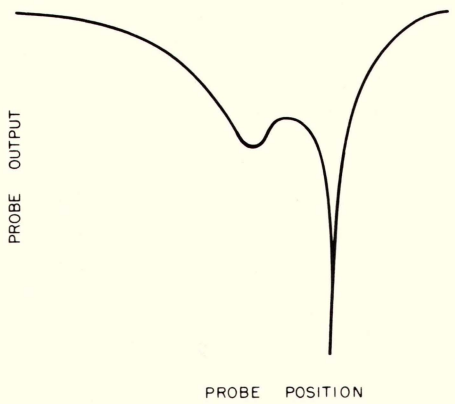


Figure 2-7. Typical Pattern of High SWR Spurious Frequency in Signal Source

2-10 IMPEDANCE MEASUREMENT RULES

Some rules of thumb that are helpful in making slotted line measurements are:

1) The shift in the minimum when the load is shorted is never more than ± one quarter wavelength.

2) If shorting the load causes the minimum to move toward the load, the load has a capacitive component.

3) If shorting the load causes the minimum to shift toward the generator, the load has an inductive component.

4) If shorting the load does not cause the minimum to move, the load is completely resistive and has a value Z_o/SWR.

5) If shorting the load causes the minimum to shift exactly one-quarter wavelength, the load is completely resistive and has a value of Z_o x SWR.

6) When the load is shorted, the minimum will always be a multiple of a half-wavelength from the load.

Shifts in voltage minima resulting from various types of loads are illustrated in Figure 2-8.

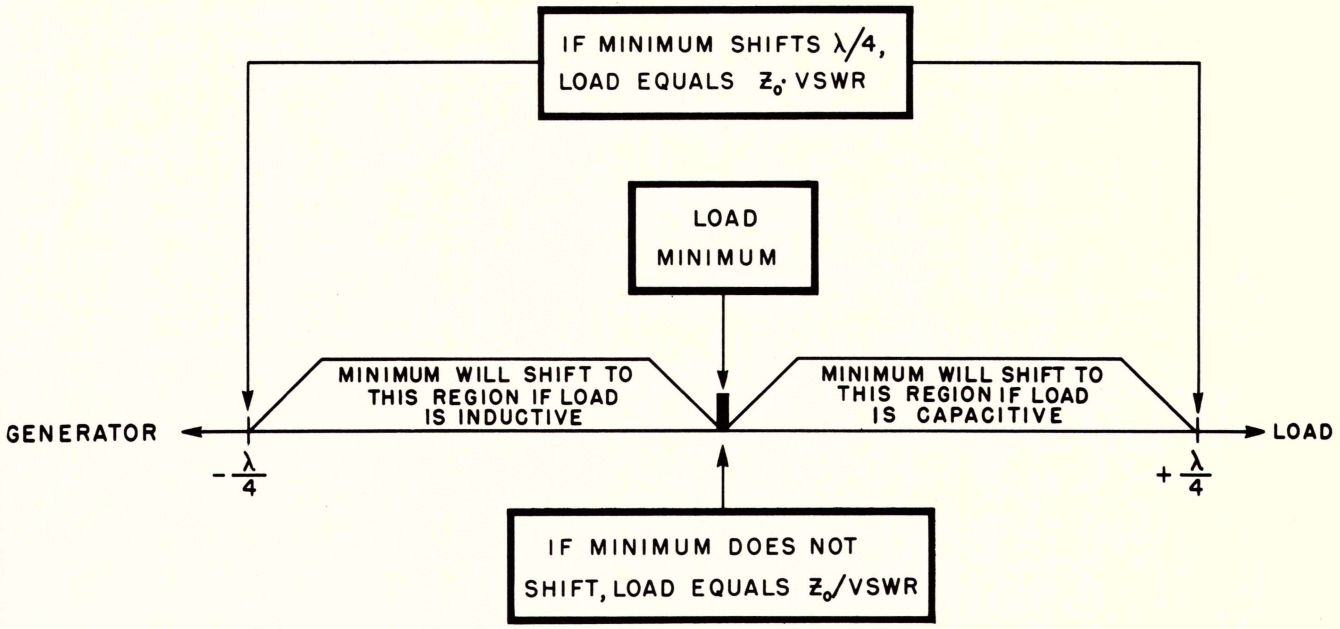

IF MINIMUM SHIFTS λ/4, LOAD EQUALS Z₀·VSWR
LOAD MINIMUM
MINIMUM WILL SHIFT TO THIS REGION IF LOAD IS INDUCTIVE
MINIMUM WILL SHIFT TO THIS REGION IF LOAD IS CAPACITIVE
GENERATOR
LOAD
-λ/4
+λ/4
IF MINIMUM DOES NOT SHIFT, LOAD EQUALS Z₀/VSWR

Figure 2-8. Summary of Rules for Impedance Measurement

2-11 IMPEDANCE MEASUREMENT PROCEDURE

The technique for performing actual impedance measurement is as follows:

1) Connect the load under test to the slotted section and measure the SWR and the position of the minimum in the standing wave pattern.

2) Replace the load with a short at the load end of the slotted line.

3) Determine the new minimum position with the line shorted.

4) The normalized load impedance may be computed by the formulas below. Refer to Figure 2-9.

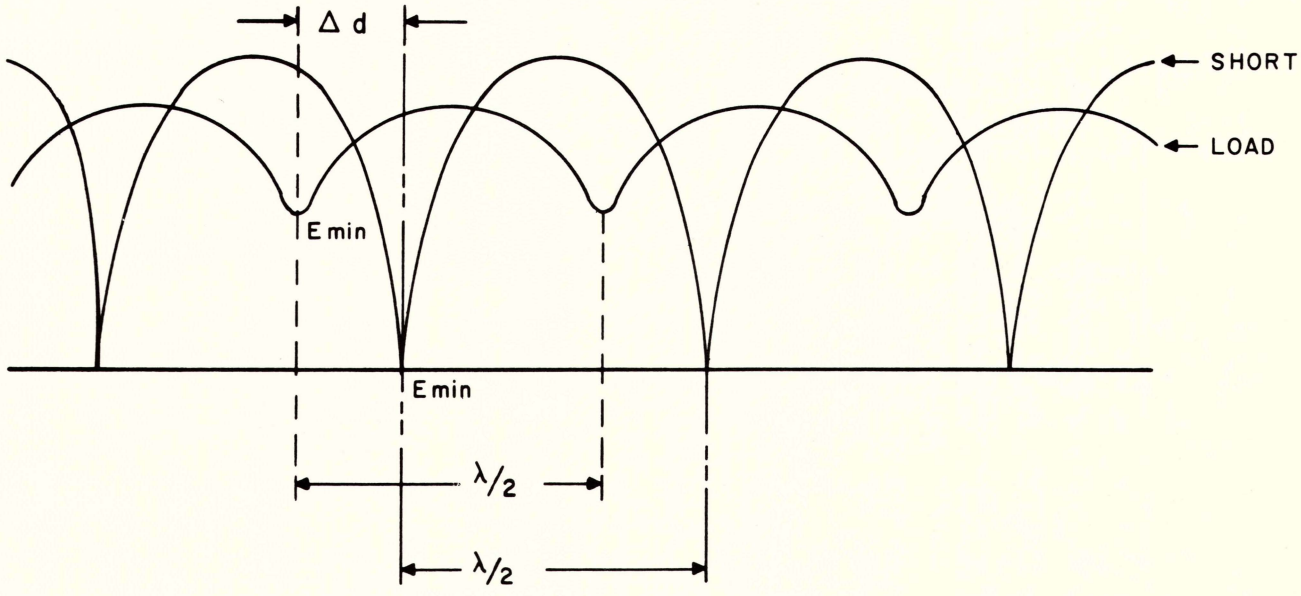


Figure 2-9. Graph Showing Standing Wave Patterns with a Load and Short

$$Z_L = \frac{1 - j\,(SWR)\,\text{Tan}\,X}{(SWR) - j\,\text{Tan}\,X}$$

$$\text{Where: } X = \frac{180° (\pm \Delta d)}{\frac{\lambda}{2}}$$

And: $\pm \Delta d$ = Shift in centimeters of the minimum point when the short is applied.

Δd takes a positive (+) sign when the minimum shifts toward the load.

Δd takes a negative (-) sign when the minimum shifts toward the generator.

$\frac{\lambda}{2}$ = One-half line or guide wavelength. It is the distance in centimeters as measured between two adjacent minima.

These calculations are based upon the assumption that no losses occur in the transmission system. For laboratory set-ups where the line lengths are short this assumption is customary. It is also assumed that the Z_O for the lines is entirely resistive.

2-12 IMPEDANCE MEASUREMENT AND THE SMITH CHART

When data is obtained from slotted line measurement, one of the most indispensable tools and certainly the simplest to use, is the Smith Chart. This chart represents an impedance coordinate system so arranged that the variable quantities in impedance relationships are conveniently displayed for the solution of transmission line problems.*

The values of resistance and reactance shown on the Smith Chart in Figure 2-10 are based upon the normalized values. The normalized impedance, resistance or reactance is obtained by dividing the actual value by the characteristic impedance of the line. For example, if the actual impedance of a 50 ohm transmission line were found to be 100 ohms at some point, the normalized impedance would be 2.

---

*Smith, P.H. "Transmission-line Calculator" Electronics, Jan. 1939, McGraw Hill.

Ragain, G.L. Ch. 2, Vol. 9 M.I.T. Rad. Lab. Series, 1948, McGraw-Hill.

The circles on the Smith Chart tangent to bottom of the chart are circles of constant and normalized resistance.

The straight line forming the vertical diameter of the chart is the line of zero reactance. To the right and left of this line are seen lines which curve away from the zero reactance line. The curved lines to the right are the lines of positive reactance $\frac{+jX.}{Z_O}$

The curved line to the left are the lines of negative reactance, $\frac{-jX.}{Z_O}$

For example, the impedance point of a line terminated by its characteristic impedance would be the center of the chart (with a normalized resistance of 1.0 and no reactive component).

In another example of actual impedance calculation:

$$Z_L = 5 + j25 \text{ ohms}$$

Normalized for a 50 ohm line would be:

$$Z_N = 0.1 + j0.5$$

2-13 PROCEDURE FOR SMITH CHART CALCULATIONS

The step by step procedure for employing the Smith Chart when solving transmission line problems is outlined below. It should be understood that there are various methods employed for entering the Smith Chart with data obtained from the slotted line, and that the method outlined in this section has been found practical and simple.

1) Set up slotted line in system.

2) Measure SWR in manner described in section 2-6.

3) Determine wavelength of transmission line (λ L). The distance as measured on slotted line between two adjacent minima is equal to one-half the wavelength of the line.

4) Find a convenient minimum point.

5) Replace load with short.

6) Measure Δd (the shift in centimeters of the minimum point with the short applied).

7) Determine the number of wavelength of shift ($\Delta\lambda$).

$$\Delta\lambda = \frac{\Delta d}{\lambda L}$$

8) Starting at center of Smith Chart draw circle with SWR as radius. Read SWR on zero reactance line down from center.

9) Enter the Smith Chart at the top and proceeding in a direction of probe movement (either toward the load or toward the generator) when the load was replaced by a short to the quantity $\Delta\lambda$ established in step 7.

10) Draw a line to the center of the chart from the $\Delta\lambda$ point.

11) The intersection of this line and the SWR circles is the normalized impedance.

12) It is important that the convention be followed of first finding the minimum reference with the load on the line and then sliding the probe to the new minimum when the line is shorted. Should it be necessary to establish the shorted minimum point first, the Smith Chart would be entered with $\Delta\lambda$ in a direction opposite to the direction of probe movement. That is, the probe movement toward the load would be entered on the chart in a directon toward the generator.

13) The following is an example to clarify the previous procedure (refer to figure 2-10):

The SWR measured is 3.3.

Distance between two adjacent minima is 15 cm. Therefore, wavelength of the line is 30 cm (λ L).

A convenient minimum is located at 22 cm.

When the line is shorted the minimum point shifts to 19 cm (toward generator).

$\Delta d = 22 - 19$

$\Delta d = 3$ cm

$$\Delta\lambda = \frac{\Delta d}{\lambda L}$$

$$\Delta\lambda = \frac{3}{30}$$

$\Delta\lambda = 0.1$ wavelength

Construct SWR circle on Smith Chart (1).

Construct radius to wavelength shift point (2).

Read normalized impedance at intersection of circle and radius (3).

In this example the normalized impedance is 0.44 + j0.63. Assuming a characteristic impedance of 50 ohms, the load impedance, Z_L, is:

$Z_L = 50\ (0.44 + j0.63)$

$Z_L = 22 + j31.5$ ohms

2-14 USING THE 415B WITH AN OSCILLOSCOPE

With the 415B RECORDER jack at normal there is a 1500-ohm resistor (R37) across the tip and ring leads of the jack. With a plug in the jack, R37 is open. For proper operation of the 415B, therefore, it is necessary to connect a 1500-ohm resistor across the tip and ring of the plug when connecting the 415B to a high-impedance instrument like an oscilloscope.

Use a three-conductor plug, such as a Switchcraft No. 60, and connect a 1500-ohm 1/4 watt resistor across the tip and ring terminals (see Figure 2-9A). Be sure the resistor is not connected across the tip and sleeve (ground); if the external 1500-ohm resistor is connected to ground, part of the meter feedback circuit will be shunted to ground.

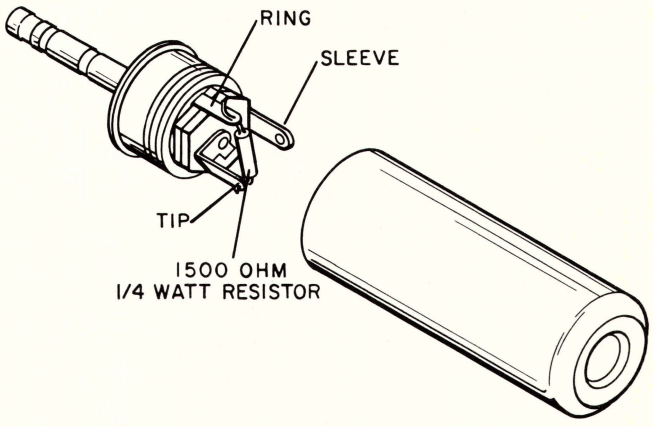


Figure 2-9A. Three-Conductor Plug Connection

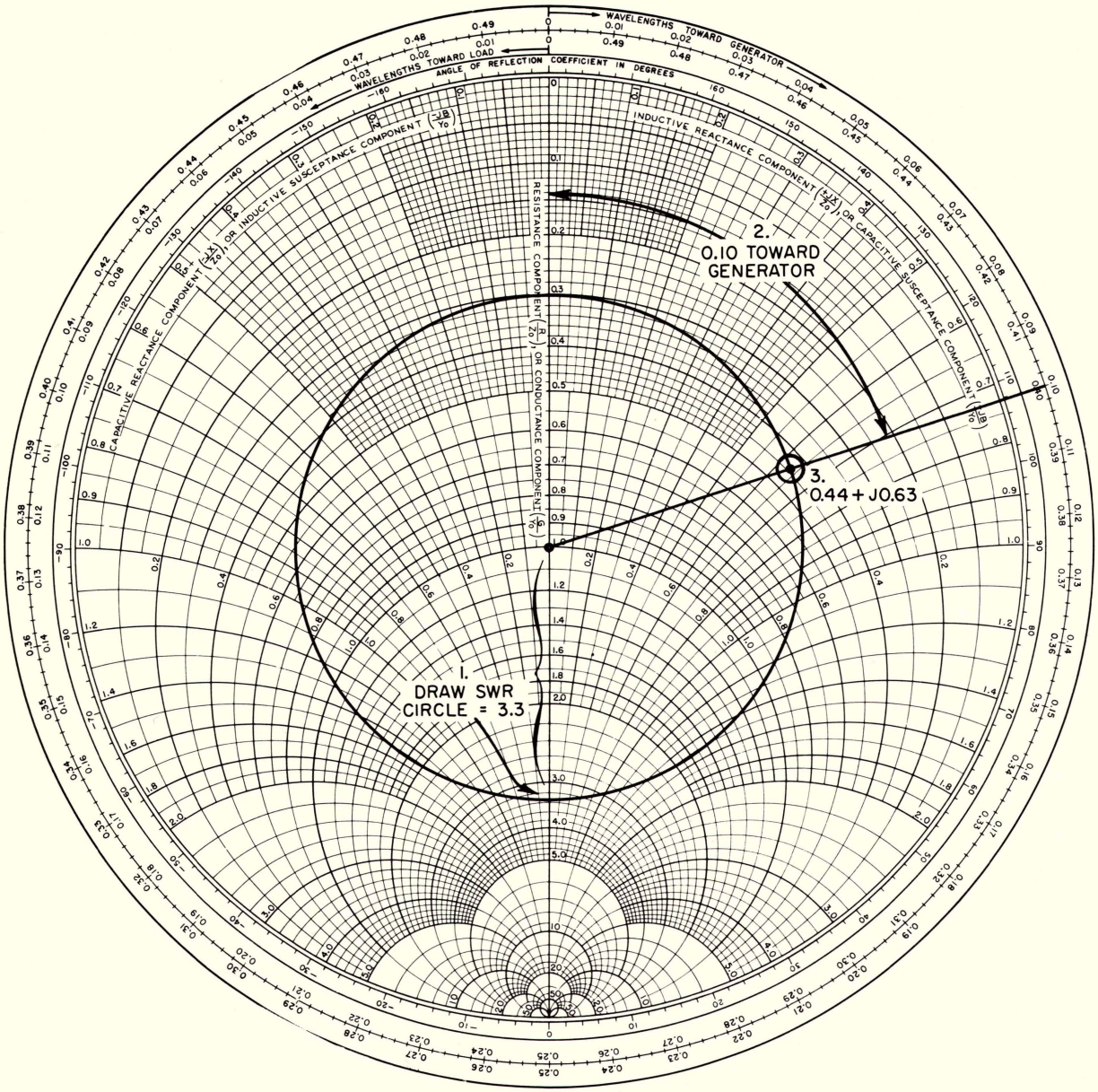

WAVELENGTHS TOWARD GENERATOR
WAVELENGTHS TOWARD LOAD
ANGLE OF REFLECTION COEFFICIENT IN DEGREES
INDUCTIVE REACTANCE COMPONENT (+jX/Zo) OR CAPACITIVE SUSCEPTANCE COMPONENT (+jB/Yo)
CAPACITIVE REACTANCE COMPONENT (-jX/Zo) OR INDUCTIVE SUSCEPTANCE COMPONENT (-jB/Yo)
RESISTANCE COMPONENT (R/Zo) OR CONDUCTANCE COMPONENT (G/Yo)
1. DRAW SWR CIRCLE = 3.3
2. 0.10 TOWARD GENERATOR
3. 0.44 + J0.63

Figure 2-10. Smith Chart Showing Normalized Impedance

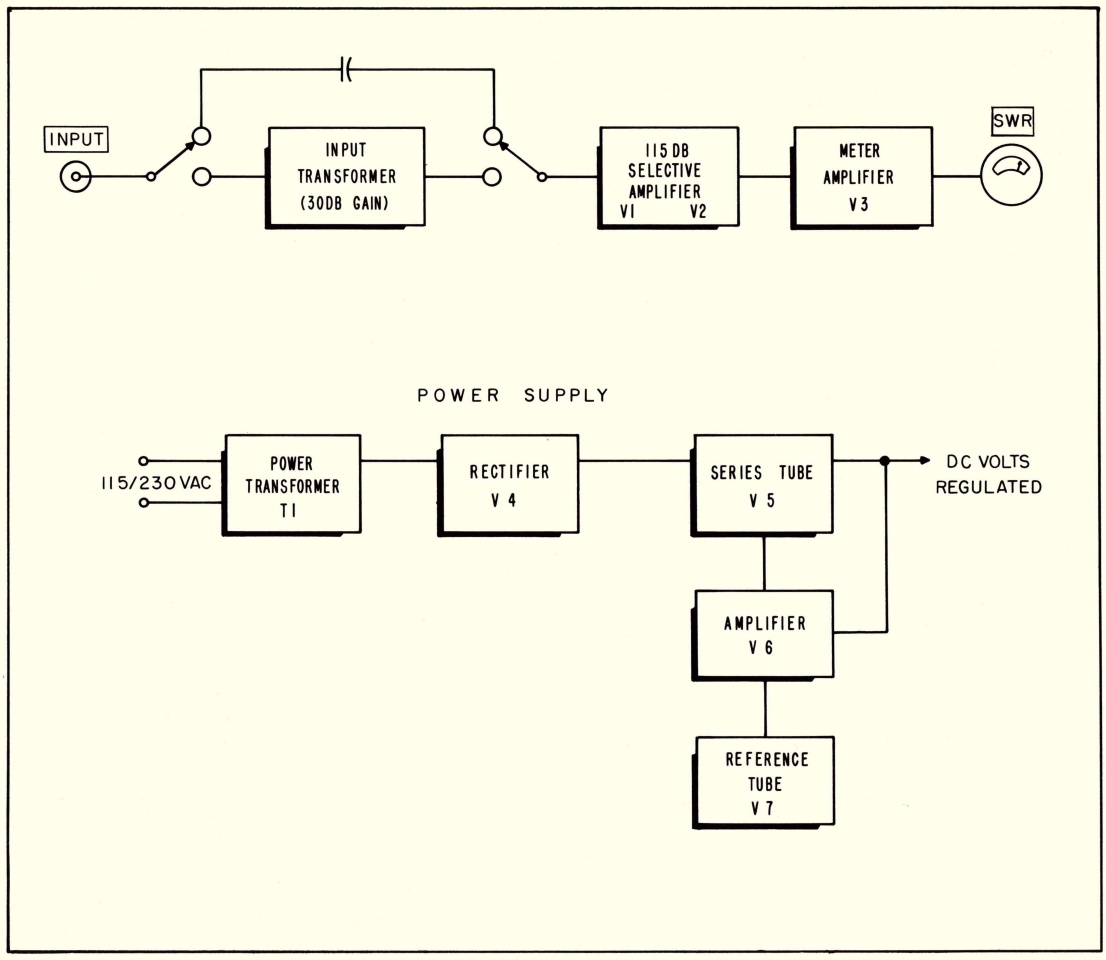


Figure 3-1. Model 415B Block Diagram

SECTION III
PRINCIPLES OF OPERATION

3-1 CIRCUIT DESCRIPTION

The Model 415B Standing Wave Indicator consists of a high-gain amplifier with very low noise level, a plug-in filter, an indicating meter and an electronic regulated power supply. All tubes of the instrument are shown in block diagram in Figure 3-1.

3-2 FREQUENCY SELECTIVE AMPLIFIER

The frequency selective amplifier consists of a step-up input transformer, T2, four resistance-coupled amplifier stages and a fourth stage drives a Fixed-frequency filter. The amplifier without the input transformer provides a total gain of 115-db gain, while T2 provides an additional 30 db.

The input circuit to an amplifier is arranged to match various external signal sources such as a crystal diode, barretter or a relatively high-impedance device (bridge circuit, etc.). When the input circuit is switched to XTAL-200KΩ the INPUT jack connects through the RANGE switch, S5, to the grid of the first amplifier stage. In the XTAL-200 Ω position, the INPUT jack connects to the primary of T2 which provides a reflected load of 200 ohms to any device connected to the INPUT jack.

In BOLO position the INPUT jack connects to the primary of the input transformer as above; except that the primary winding is now returned to R2 and R3 which provide dc operating bias to any 200 detector element connected to the INPUT. Diodes CR3 through CR6 maintain the voltage at the INPUT jack at a low level to reduce the transient current from C2 when a detector element is connected. The HIGH-LOW switch shunts the bias source with R1 so that two different values of bias (4.3 and 8.7 ma) may be used. The MONITOR jack is supplied so that an external milliammeter may be used to measure the bias current passing through the detector.

The RANGE switch, S5, consists of a three-section step attenuator which changes the gain of the amplifier in 20-db steps. However, to obtain square law meter calibration, the steps are calibrated 10 db on the front panel. The three sections of the attenuator are located in the grid circuits of the first three amplifier stages, V1A, B and V2A. The third section provides the first attenuation step, the second section the second attenuation step and the first section provides the remaining four attenuation steps. Selected precision resistors are used throughout the range switch. Because of the extremely high gain in this amplifier, the grounding of all parts in the first and second stages is very critical and specially indicated on the schematic diagram. The heavy lines indicate common negative tie points which in turn are together and connected to chassis only at J1.

The output level from the amplifier is controlled by a two-section potentiometer (GAIN, R22A and VERNIER, R22B.) in the grid circuit of the last amplifier stage. The potentiometers are connected in series, one providing approximately 25 db (12.5 db on the meter scale) of control for coarse adjustments, the other approximately 1.5 db (0.75 db on the meter scale) of control for fine adjustments.

Switch S4a between the second and third amplifier stages, when in the -5 db position, reduces the sensitivity of the amplifier to decrease the SWR meter indication by 5 db so that down-scale meter readings may be made upscale on the next lower range of the RANGE switch.

To make the amplifier frequency selective, the plate circuit of the last stage is loaded with parallel resonant circuit, Z1, having an effective Q between 20 and 30. The tuned circuit allows a 1000-cps signal to pass unattenuated, while the decreased impedance at off resonant frequencies attenuates these frequencies considerably. The effective bandwidth is approximately 40 cycles at the half-power points.

3-3 METER CIRCUIT

The 1000-cps signal from the selective amplifier is applied to a two-stage feedback amplifier which operates crystal rectifiers CR1, CR2 and the indicating meter M1. To assure linear operation, negative feedback is used around both the amplifier and the rectifier circuit. A 0.46-volt rms signal is required at the first grid of V3 to obtain a full scale meter indication. The signal from the second plate of V3 is fed to crystal diode CR2 which allows current to flow through R37 and the meter during the negative half of the signal cycle. During the positive half cycle the current returns through CR1 and R36.

Front panel selector S4, when set to the EXPAND position, applies a dc bucking voltage to the meter rectifiers so that a meter reading is forced off-scale, i.e., downward. The amplifier sensitivity must then be increased to obtain an upscale reading; which can then be read on the expanded meter scales.

3-4 POWER SUPPLY

The power supply consists of a power transformer with a single high-voltage winding feeding a full wave rectifier and electronic voltage regulator supplying dc to all the circuits of the standing wave indicator. The voltage regulator circuit maintains constant output voltage with wide changes in load current and line voltage.

V5, V6 and V7 constitute the voltage regulator circuit. V7 is a constant-voltage tube which provides the reference bias for V6. V5 operates as a series tube, or variable resistor, controlled by the voltage at the grid of V6. If the regulated B+at the cathode of V5 tends to increase, the grid voltage for V6 increases causing V6 to draw more current. This lowers the plate voltage of V6 and therefore the grid voltage of V5 and results in greater plate resistance for V5. The greater plate resistance causes a greater voltage drop across V5, compensating for the increased voltage at its cathode and resulting in a substantially constant voltage output.

If the regulated B+ voltage tends to decrease, the reverse of the above action occurs, also tending to maintain the cathode voltage substantially constant. Ripple in the output voltage is coupled to the grid of V6 by capacitor C12. Variations in the dc voltage are coupled to the grid of V6 through the voltage divider R44, R45 and R46. The bias for V6 and the level of the output voltage from V5 are determined by the setting of R45.

The heaters of amplifier tubes V1, V2 and V3 are operated from a positive biased heater winding to reduce hum pickup from the heaters of these tubes. The bias voltage is obtained from a 10 volt point on the voltage divider stick R44, R46 and R48 in the power supply.

SECTION IV
MAINTENANCE

4-1 INTRODUCTION

This section contains instructions for adjustment and repair of the hp Model 415B Standing Wave Indicator. The information in this section is as follows:

4-2 Trouble Shooting the 415B
4-3 Replacing Tubes
4-4 Replacing Crystal Diodes
4-5 Range Switch Repairs
4-6 Equipment Required for Test and Adjustment
4-7 Test and Adjustment Procedure (General)
4-8 Set Meter Mechanical Zero
4-9 Adjust Regulated Power Supply
4-10 Check Monitor Jack
4-11 Testing Tuned Filter
4-12 Check Sensitivity
4-13 Check Range Tracking
4-14 Check Noise Level
4-15 Calibrate Expanded Scale
4-16 Check -5DB Switch

4-2 TROUBLE SHOOTING THE 415B

The Model 415B is basically a high-gain, tuned amplifier with a "relative" indicating voltmeter. The instrument has few critical circuits. The maximum sensitivity may decrease as the tubes weaken with age but the accuracy will not be affected. Only adjustment of the power supply and/or recalibration of the EXPANDED scale is necessary after tube replacement.

The accuracy of the meter calibration is largely determined by crystal diodes CR1 and CR2. The mechanical tracking of the meter movement and the linearity of the amplifier affect meter calibration accuracy to a lesser degree. The amplifier linearity does not normally change.

Any unstable condition can usually be traced to the power supply. The power supply can be quickly checked by measuring the dc output voltage and by noting the noise level indication on the 415B meter. An incorrect regulated voltage and/or a high residual noise level can be corrected by adjustment or by changing tubes. A high residual noise level that cannot be traced to the power supply can usually be corrected by replacing tube V1.

Individual stage gain measurements can be used to analyze an inoperative instrument. Gain can be checked by applying a small voltage (0.01 volt) from an audio oscillator to each stage in turn and measuring the stage output voltage. Set the audio oscillator to the same frequency as filter Z1 (usually 1000 cps). The approximate gain from each stage is as follows:

STAGE	DB GAIN (approx.)
Input Transformer	30
V1a	34
V1b	27.5
V2a	31
V2b	22
V3	***

***Approximately a 0.46 volt rms signal at the input of V3 will give a full scale meter deflection.

4-3 REPLACING TUBES

The tubes in the Model 415B can be replaced without making any adjustments except for those in the regulated power supply. The EXPANDED scale calibration should be checked after replacement of V3. After changing tubes in the power supply, the output voltage of the power supply should be checked and adjusted. Control R45 should be adjusted to set the dc voltage between the chassis and the cathode of the series regulator tube.

When replacing V1, select a tube that minimizes the noise indication and if possible the microphonics also.

4-4 REPLACING CRYSTAL DIODES

Use diodes with a high front-to-back resistance ratio of several hundred to one or better when replacing diodes CR1 and CR2. Adjustments are not necessary following replacement of CR1 and CR2 except that the calibration of the EXPANDED scale should be checked.

4-5 RANGE SWITCH REPAIRS

The precision resistors on the RANGE switch are selected and matched for accuracy during manufacture. Attempted replacement of individual resistors is usually not practical. Replacement of the entire switch assembly is recommended as a time-saving measure and guarantee of maintaining the original calibration accuracy.

4-6 EQUIPMENT REQUIRED FOR TEST AND ADJUSTMENT

The following test equipment (or equivalent) may be used for tests and adjustments.

---An hp Model 200CD Wide Range Oscillator

---An hp Model 400D, 400H, or 400L ac vtvm

---A pair of hp Model 350B Attenuators

---An hp Model 410B Vacuum Tube Voltmeter

---An adjustable line voltage source with meter

---An 0-10 dc milliammeter with a known internal resistance and connected to a three-circuit phone plug. Connect the positive terminal of the meter to the "ring" of a 1/4 inch diameter "tip-ring-sleeve" phone plug and the negative terminal to the "tip".

---A BNC connector with a 1 watt composition resistor connected between the center contact and the outer shell. The resistor value plus the resistance of the 0-10 dc milliammeter must equal 200 ohms.

---A pair of hp Model 11000A banana plug to banana plug shielded cables and an hp Model 11001A banana plug to BNC shielded cable.

4-7 TEST AND ADJUSTMENT PROCEDURE (General)

The specifications for your hp Model 415B Standing Wave Indicator are given in the front of this manual. The following test procedure contains extra checks to help you analyze a particular instrument. These extra checks and the data they contain cannot be considered as specifications.

NOTE

The Model 415B is calibrated for use with square-law detectors. The output of these detectors is proportional to power. In the following test procedures, the detector is not used, therefore the 415B will indicate only half the actual db change in input voltage. For example (Figure 4-1), an increase of 20 db in the 350B setting will read 10 db lower on the 415B.

4-8 SET METER MECHANICAL ZERO

Turn the 415B ON long enough for the meter movement to reach the ambient temperature within the cabinet. Turn the instrument OFF and set the mechanical zero while the meter is still warm.

Rotate the meter mechanical zero adjusting screw clockwise until the meter pointer is traveling to the left toward 1.3 on the EXPANDED SWR scale and stop at 1.3. If you overshoot, continue rotating the adjustment screw clockwise,and again approach from the high side of the scale. The adjustment screw should not be turned counterclockwise during any part of this adjustment.

4-9 ADJUST REGULATED POWER SUPPLY

Connect the 410B VTVM between cathode (pin 3) of series regulator tube V5 and chassis ground. Adjust control R45 for a voltmeter reading of 245 volts dc with the line voltage set to 115 volts. As the line voltage is varied between 103 and 127 volts, the reading on the voltmeter will normally not change by more than $\pm 1\%$.

4-10 CHECK MONITOR JACK

Insert the phone plug from the 0-10 dc milliammeter into the MONITOR jack. Attach the BNC connector with resistor to the INPUT. The milliammeter connections and the resistor value are given in paragraph 4-6.

Set the INPUT SELECTOR switch to BOLO. The milliammeter will usually indicate 8.4 ± 0.4 milliamperes with the BOLO BIAS CURRENT switch in the HIGH position or 4.3 ± 0.3 milliamperes with the switch in the LOW position.

If the currents are incorrect, check resistors R1, R2, and R3 as well as the power supply voltage.

4-11 TESTING TUNED FILTER

The plug-in tuned audio filter assembly which is part of an hp Model 415B Standing Wave Indicator can be tested for resonant frequency and Q as follows:

Plug filter into 415B, set 415B INPUT Selector to Crystal, and connect an audio oscillator to 415B INPUT. Adjust frequency and amplitude of audio oscillator signal to get a peak indication on the 415B meter. The peak indication should occur within ±2% of the frequency marked on the filter. The peak may be fairly broad, but resonant frequency can be determined by measuring the frequencies that cause the 415B indication to drop 1.5 db on each side of the response curve. Consider the frequency midway between the two frequencies as the resonant frequency.

Compute the filter bandpass: the bandpass is the difference between the two frequencies measured at -1.5 db from the peak indication on each side of the response curve as indicated on the 415B meter. Divide the resonant frequency by the bandpass. The Q of filters from the 415B should be about 25 to 30.

4-12 CHECK SENSITIVITY

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the attenuator set output.

NOTE

Several precautions must be used if you wish accurate results when using the Figure 4-1 test set-up. At least 20 db of attenuation should be inserted in the attenuator set at all times. The maximum attenuation inserted by either attenuator should not be over 80 db. The Model 415B chassis connection through the third wire in the NEMA type power cord should be disabled by using a three-prong to two-prong polarized adapter. The only ground connection to the 415B must be through the shielded cable from the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to 0 DB. Set the input switch to XTAL 200 ohms and the METER SCALE switch to the NORMAL position.

Tune the audio oscillator to the Model 415B filter frequency as indicated by maximum deflection of the 415B meter. Adjust the audio oscillator output to obtain a full scale indication on the 415B. The indication on the ac vtvm should be 0.1 volt or less.

If the basic sensitivity is found to be low, try several replacement tubes for V1, V2, and/or V3.

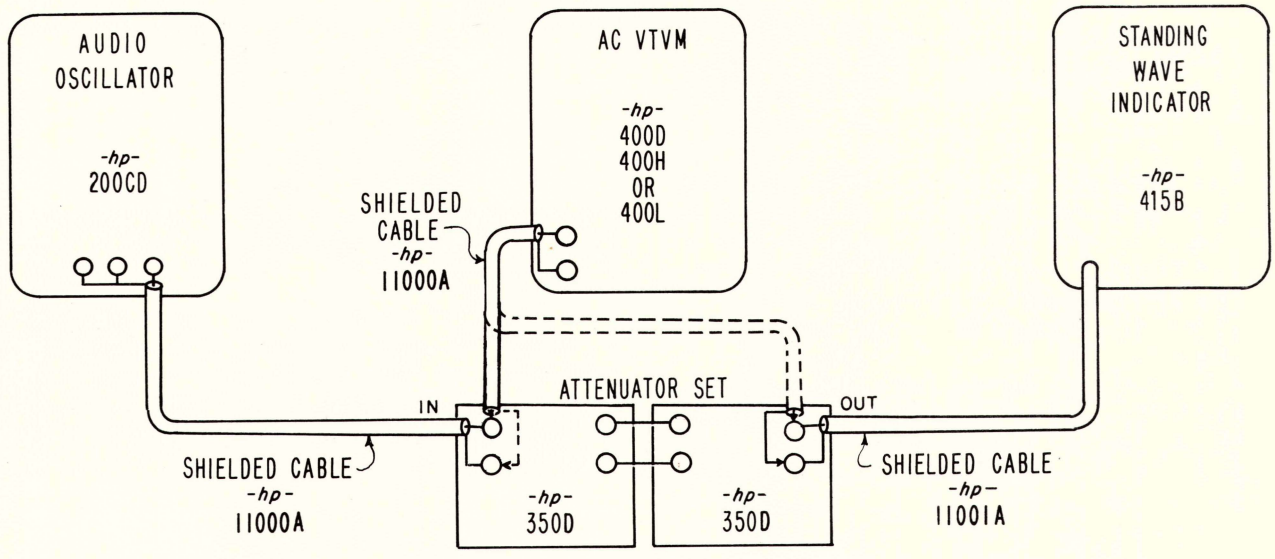


Figure 4-1. Instrument Connections for 415B Test and Adjustment

4-13 CHECK RANGE TRACKING

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the input of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to 0 DB. Set the input switch to XTAL 200 Ω and the METER SCALE switch to NORMAL.

Tune the audio oscillator to the 415B filter frequency as indicated by maximum deflection of the 415B meter. Adjust the audio oscillator output for a full scale indication of "0" on the db scale. Note the indication on the ac vtvm and adjust the output of the audio oscillator to keep this reading constant.

Add 20 db attenuation in the attenuator set and rotate the 415B RANGE switch to 10 DB. The 415B meter should again indicate 0 db ± 0.1 db.

Repeat this procedure for each step of the 415B RANGE switch. The 415B meter should indicate within ± 0.2 db of the full scale 0 db mark on all six ranges. Adjacent ranges should read within ± 0.1 db of each other.

4-14 CHECK NOISE LEVEL

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the output of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to 0 DB. Set the input switch to XTAL 200 Ω and the METER SCALE switch to NORMAL.

Tune the audio oscillator to the 415B filter frequency as indicated by maximum deflection of the 415B meter. Adjust the audio oscillator output to obtain an indication of 0.03 volts on the ac vtvm. Note the indication on any convenient scale of the 415B. This indication will be used as a "reference".

Disconnect the ac vtvm and the audio oscillator. Set both 350B attenuators for 110 db attenuation. This is the only exception to the precaution given in the NOTE for Figure 4-1. Switch the 415B RANGE switch to 60 DB.

The indication on the 415B should be less than (to the left of) the "reference" indication noted above.

4-15 CALIBRATE EXPANDED SCALE

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the input of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to 0 DB. Set the input switch to XTAL 200 Ω and the METER SCALE switch to EXPAND.

Tune the audio oscillator to the 415B filter frequency as indicated by maximum deflection of the 415B meter. Check that the attenuator set is introducing at least 20 db of the attenuation and adjust the output of the audio oscillator to provide a full scale indication.

Attenuate the signal 4 db with the attenuator set. The 415B should now indicate 2 DB on the EXPANDED DB scale. If not, repeat the following procedure until a 4 db attenuation drops the meter indication from full scale to exactly the 2 db mark: ---Note the meter deviation from the 2 db mark and adjust R33 to get an equal error on the other side of the 2 db mark. Readjust attenuator set and signal for a full scale deflection, then attenuate signal 4 db. Repeat until no additional adjustment is necessary.

4-16 CHECK -5 DB SWITCH

Connect the test equipment as shown in Figure 4-1. Connect the ac vtvm to the input of the attenuator set.

Rotate the Model 415B GAIN control fully clockwise and the RANGE switch to any convenient position. Set the input switch to XTAL 200 Ω and the METER SCALE switch to NORMAL.

Tune the audio oscillator to the 415B filter frequency as indicated by maximum deflection of the 415B meter. Check that the attenuator set is introducing at least 30 db of attenuation and adjust the output of the audio oscillator to provide a "full scale" indication.

Increase the input signal to the Model 415B 10 db by decreasing the setting on the attenuator. Switch the meter scale switch to the -5 DB position. The 415B indication should remain at the "full scale" point.

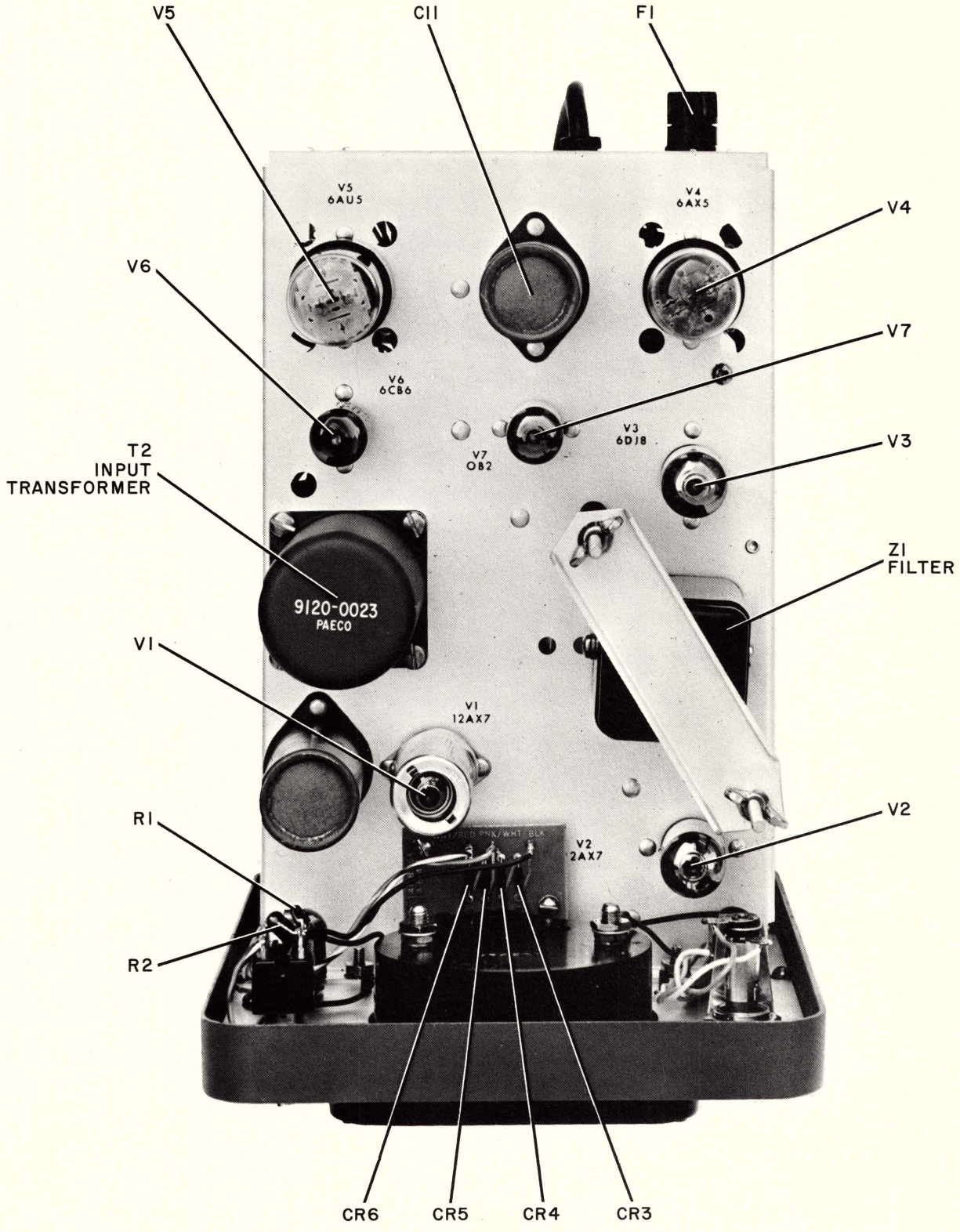


Figure 4-2. Model 415B Top View

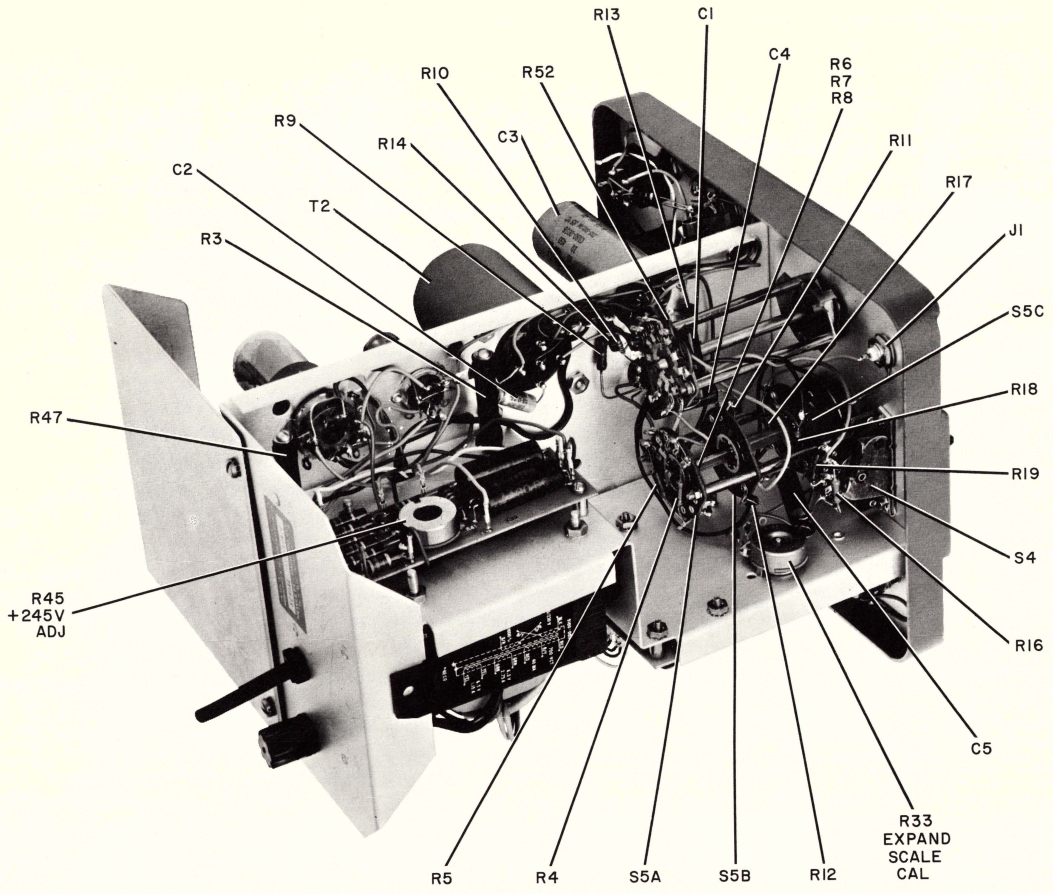


Figure 4-3. Model 415B, Bottom View

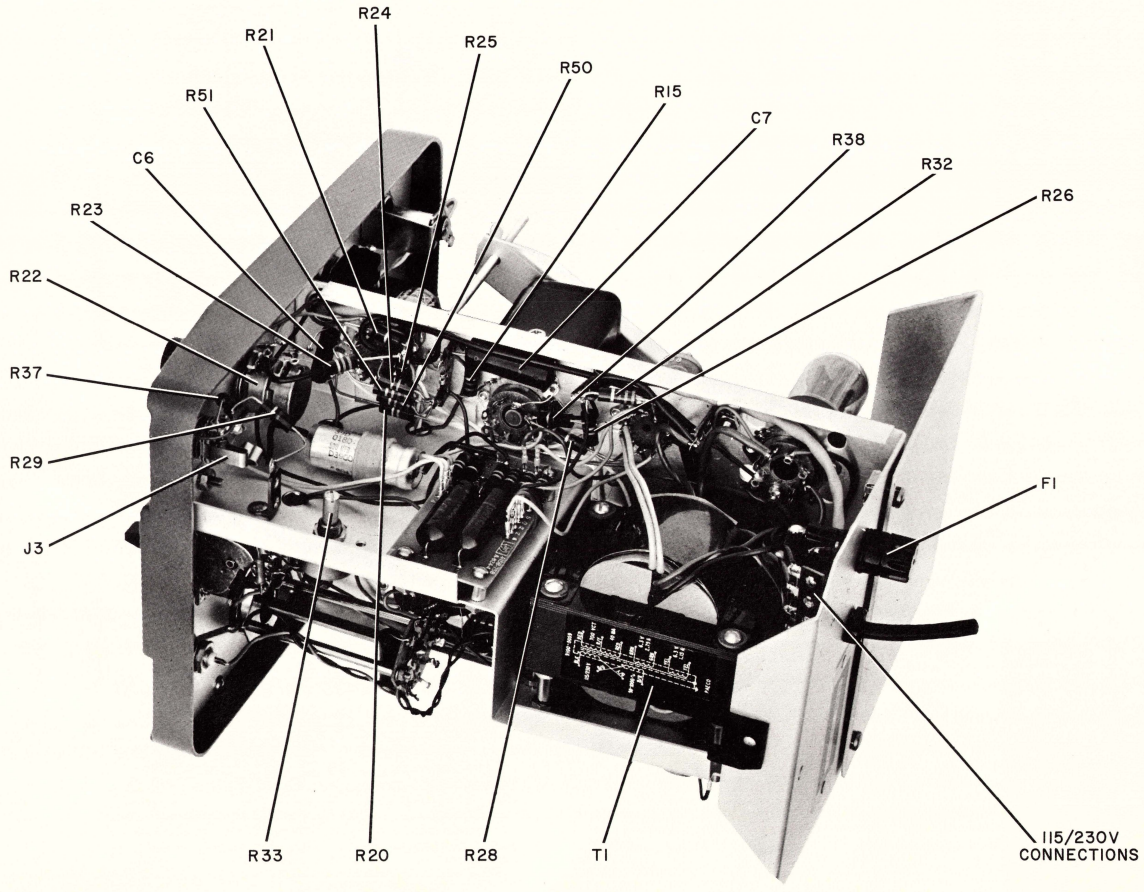


Figure 4-4. Model 415B, Right Side

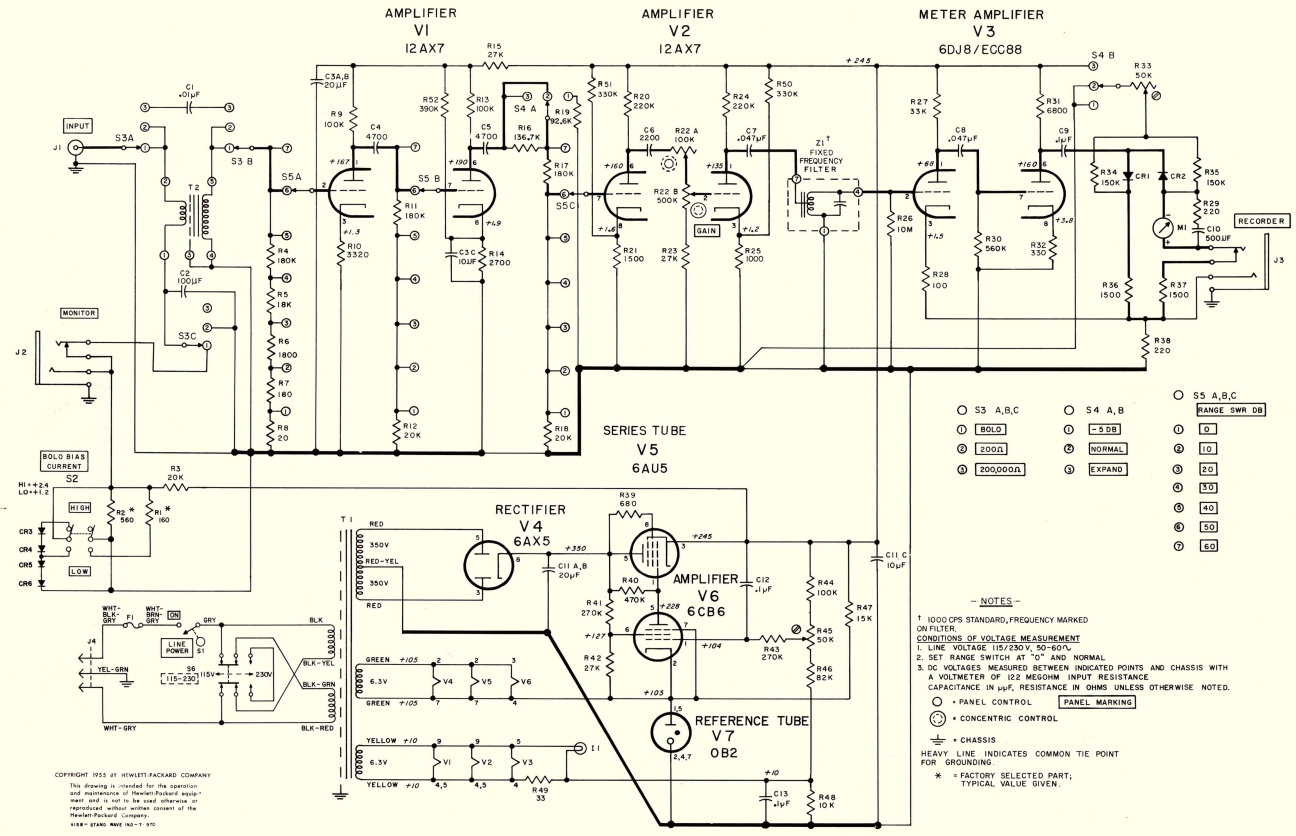


Figure 4-5. Model 415B Standing Wave Indicator

SECTION V
REPLACEABLE PARTS

5-1. INTRODUCTION

5-2. This section contains information for ordering replaceable parts. Table 5-1 gives the meanings of abbreviations and reference designations used in the table of replaceable parts. Table 5-2 is the table of replaceable parts and is organized as follows:

a. Electrical assemblies and their component parts in alpha-numerical order by reference designation.

b. Chassis-mounted parts in alpha-numerical order by reference designation.

c. Miscellaneous parts.

5-3. The information given for each part consists of:

a. The Hewlett-Packard part number.

b. Total quantity in the instrument.

c. Description of the part.

d. Typical manufacturer of the part in a 5-digit code.

e. The manufacturer's number for the part.

Total quantity for each part is given only once — at the first appearance of the part number.

5-4. Table 5-3 contains the names and addresses that correspond to the manufacturer's code numbers.

5-5. ORDERING INFORMATION

5-6. To order a replacement part, address order or inquiry to your local Hewlett-Packard sales and service office (see lists at rear of this manual).

5-7. Specify the following information for each part: Model and complete serial number of instrument, Hewlett-Packard part number, circuit reference designation, and complete description of the part.

Table 5-1. Reference Designations and Abbreviations Used in Parts List

REFERENCE DESIGNATORS

A	= assembly	F	= fuse	P	= plug	V	= vacuum tube, neon bulb, photocell, etc.
B	= motor	FL	= Filter	Q	= transistor		
BT	= battery	J	= jack	R	= resistor		
C	= capacitor	K	= relay	RT	= thermistor	VR	= voltage regulator
CP	= coupler	L	= inductor	S	= switch		
CR	= diode	LS	= loud speaker	T	= transformer	W	= cable
DL	= delay line	M	= meter	TB	= terminal board	X	= socket
DS	= device signaling (lamp)	MK	= microphone	TP	= test point	Y	= crystal
E	= misc electronic part	MP	= mechanical part	U	= integrated circuit	Z	= tuned cavity, network

ABBREVIATIONS

A	= amperes	H	= henries	N/O	= normally open	RMO	= rack mount only
AFC	= automatic frequency control	HDW	= hardware	NOM	= nominal	RMS	= root-mean square
		HEX	= hexagonal	NPO	= negative positive zero (zero temperature coefficient)	RWV	= reverse working voltage
AMPL	= amplifier	HG	= mercury				
		HR	= hour(s)			S-B	= slow-blow
BFO	= beat frequency oscillator	Hz	= Hertz			SCR	= screw
				NPN	= negative-positive-negative	SE	= selenium
BE CU	= beryllium copper	IF	= intermediate freq			SECT	= section(s)
BH	= binder head	IMPG	= impregnated	NRFR	= not recommended for field replacement	SEMICON	= semiconductor
BP	= bandpass	INCD	= incandescent			SI	= silicon
BRS	= brass	INCL	= include(s)			SIL	= silver
BWO	= backward wave oscillator	INS	= insulation(ed)	NSR	= not separately replaceable	SL	= slide
		INT	= internal			SPG	= spring
						SPL	= special
CCW	= counterclockwise	K	= kilo = 1000	OBD	= order by description	SST	= Stainless steel
CER	= ceramic					SR	= split ring
CMO	= cabinet mount only			OH	= oval head	STL	= steel
COEF	= coefficient	LH	= left hand	OX	= oxide		
COM	= common	LIN	= linear taper				
COMP	= composition	LK WASH	= lock washer	P	= peak	TA	= tantalum
COMPL	= complete	LOG	= logarithmic taper	PC	= printed circuit	TD	= time delay
CONN	= connector	LPF	= low pass filter	PF	= picofarads = 10^{-12} farads	TGL	= toggle
CP	= cadmium plate					THD	= thread
CRT	= cathode-ray tube			PH BRZ	= phosphor bronze	TI	= titanium
CW	= clockwise	M	= milli = 10^{-3}	PHL	= Phillips	TOL	= tolerance
		MEG	= meg = 10^{6}	PIV	= peak inverse voltage	TRIM	= trimmer
DEPC	= deposited carbon	MET FLM	= metal film			TWT	= traveling wave tube
DR	= drive	MET OX	= metallic oxide	PNP	= positive-negative-positive		
		MFR	= manufacturer				
ELECT	= electrolytic	MHz	= mega Hertz	P/O	= part of	μ	= micro = 10^{-6}
ENCAP	= encapsulated	MINAT	= miniature	POLY	= polystrene		
EXT	= external	MOM	= momentary	PORC	= porcelain		
		MOS	= metalized substrate	POS	= position(s)	VAR	= variable
F	= farads			POT	= potentiometer	VDCW	= dc working volts
FH	= flat head	MTG	= mounting	PP	= peak-to-peak		
FIL H	= Fillister head	MY	= "mylar"	PT	= point		
FXD	= fixed			PWV	= peak working voltage	W/	= with
						W	= watts
G	= giga (10^{9})	N	= nano (10^{-9})	RECT	= rectifier	WIV	= working inverse voltage
GE	= germanium	N/C	= normally closed	RF	= radio frequency		
GL	= glass	NE	= neon	RH	= round head or right hand	WW	= wirewound
GRD	= ground(ed)	NI PL	= nickel plate			W/O	= without

Table 5-2. Replaceable Parts

Reference Designation	HP Part Number	Qty	Description	Mfr Code	Mfr Part Number
C1	0160-0002	23	C:FXD MY 0.01 UF 10% 600VDCW	56289	106P10396PMD
C2	0180-0039	1	C:FXD AL ELECT 100 UF +75-10% 12VDCW	56289	30D107G012CC2-DSM
C3	0180-0016	2	C:FXD AL ELECT 3X10 UF +50-20% 450VDCW	71471	TYPE AEF E3C 255
C4	0160-0010	2	C:FXD MY 0.0047UF 10% 600VDCW	28480	0160-0010
C5	0160-0010		C:FXD MY 0.0047UF 10% 600VDCW	28480	0160-0010
C6	0160-0007	1	C:FXD MY 0.0022 UF 10% 600VDCW	56289	160P22296 PMD
C7	0160-0005	2	C:FXD PAPER MY 0.047UF 10% 600VDCW	28480	0160-0005
C8	0160-0005		C:FXD PAPER MY 0.047UF 10% 600VDCW	28480	0160-0005
C9	0160-0013	3	C:FXD MY 0.1 UF 10% 400VDCW	56289	160P10494-PMD
C10	0180-0001	1	C:FXD AL ELECT 500 UF -10+250% 15VDCW	56289	(34D)D39007-DSB
C11	0180-0016		C:FXD AL ELECT 3X10 UF +50-20% 450VDCW	71471	TYPE AEF E3C 255
C12	0160-0013		C:FXD MY 0.1 UF 10% 400VDCW	56289	160P10494-PMD
C13	0160-0013		C:FXD MY 0.1 UF 10% 400VDCW	56289	160P10494-PMD
CR1	1910-0016	2	DIODE:GERMANIUM 100MA/0.85V 60PIV	93332	D2361
CR2	1910-0016		DIODE:GERMANIUM 100MA/0.85V 60PIV	93332	D2361
CR3	1901-0025	4	DIODE:SILICON 100MA/1V	07263	FD 2387
CR4	1901-0025		DIODE:SILICON 100MA/1V	07263	FD 2387
CR5	1901-0025		DIODE:SILICON 100MA/1V	07263	FD 2387
CR6	1901-0025		DIODE:SILICON 100MA/1V	07263	FD 2387
F1	2110-0312	1	FUSE:CARTRIDGE 1 AMP 250V SLOW-BLOW (FOR 115V OPERATION)	71400	MDL-1
F1	2110-0202	1	FUSE:0.50A 250V SLOW-BLOW	75915	313.500S
F1			(FOR 230V OPERATION)		
I1	2140-0009	1	LAMP:INCANDESCENT 6.3V 0.15 AMPS	08806	47(BRASS BASE)
J1	1250-0083	1	CONNECTOR:BNC (CABINET MODEL)	02660	31-221-1020
J1	1250-0001	1	CONNECTOR:RF BNC BULKHEAD MOUNT JACK	28480	1250-0001
J1			(RACK MODEL)		
J2	1251-0070	2	JACK:PHONE	82389	2J-1581
J3	1251-0070		JACK:PHONE	82389	2J-1581
J4	1251-2357	1	SOCKET:3-PIN MALE POWER RECEPTACLE	82389	EAC-301
M1	1120-0044	1	METER:0-1 MA	65092	801
R1	0758-0025	1	R:FXD MET OX 160 OHM 5% 1/2W	28480	0758-0025
R1			FACTORY SELECTED PART		
R2	0689-5615	1	R:FXD COMP 560 OHM 5% 1W FACTORY SELECTED PART	01121	GB 5615
R3	0816-0018	1	R:FXD WW 20K OHM 5% 10W	28480	0816-0018
R4	0727-0218	3	R:FXD DEPC 180K OHM 1% 1/2W	28480	0727-0218
R5	0727-0170	1	R:FXD DEPC 18K OHM 1% 1/2W	28480	0727-0170
R6	0727-0112	1	R:FXD DEPC 1800 OHM 1% 1/2W	28480	0727-0112
R7	0727-0050	1	R:FXD DEPC 180 OHM 1% 1/2W	28480	0727-0050
R8	0727-0012	1	R:FXD DEPC 20 OHM 1% 1/2W	28480	0727-0012
R9	0760-0009	1	R:FXD MET OX 100K OHM 2% 1W	28480	0760-0009
R10	0690-3321	1	R:FXD COMP 3300 OHM 10% 1W	01121	GB 3321
R11	0727-0218		R:FXD DEPC 180K OHM 1% 1/2W	28480	0727-0218
R12	0727-0173	2	R:FXD DEPC 20K OHM 1% 1/2W	28480	0727-0173
R13	0690-1041	2	R:FXD COMP 100K OHM 10% 1W	01121	GB 1041
R14	0690-2721	1	R:FXD COMP 2700 OHM 5% 1/4W	01121	GB 2721
R15	0690-2731	3	R:FXD COMP 27K OHM 10% 1W	01121	GB 2731
R16	0727-0216	1	R:FXD DEPC 136.7K OHM 1% 1/2W	28480	0727-0216
R17	0727-0218		R:FXD DEPC 180K OHM 1% 1/2W	28480	0727-0218
R18	0727-0173		R:FXD DEPC 20K OHM 1% 1/2W	28480	0727-0173
R19	0727-0205	1	R:FXD DEPC 92.6K OHM 1% 1/2W	28480	0727-0205
R20	0690-2241	2	R:FXD COMP 220K OHM 10% 1W	01121	GB 2241
R21	0690-1521	3	R:FXD COMP 1500 OHM 10% 1W	01121	GB 1521
R22	2100-0071	1	R:VAR COMP 500K 100K OHM	28480	2100-0071
R23	0690-2731		R:FXD COMP 27K OHM 10% 1W	01121	GB 2731
R24	0690-2241		R:FXD COMP 220K OHM 10% 1W	01121	GB 2241
R25	0690-1021	1	R:FXD COMP 1000 OHM 10% 1W	01121	GB 1021
R26	0690-1061	1	R:FXD COMP 10 MEGOHM 10% 1W	01121	GB 1061
R27	0690-3331	1	R:FXD COMP 33K OHM 10% 1W	01121	GB 3331
R28	0690-1011	1	R:FXD COMP 100 OHM 10% 1W	01121	GB 1011
R29	0690-2211	2	R:FXD COMP 220 OHM 10% 1W	01121	GB 2211
R30	0690-5641	1	R:FXD COMP 560K OHM +10% 1W	01121	GB 5641
R31	0690-6821	1	R:FXD COMP 6800 OHM 10% 1W	01121	GB 6821
R32	0690-3311	1	R:FXD COMP 330 OHM 10% 1W	01121	GB 3311
R33	2100-0013	1	R:VAR COMP 50K OHM LIN 1/2W	28480	2100-0013
R34	0690-1541	2	R:FXD COMP 150K OHM 10% 1W	01121	GB 1541
R35	0690-1541		R:FXD COMP 150K OHM 10% 1W	01121	GB 1541
R36	0690-1521		R:FXD COMP 1500 OHM 10% 1W	01121	GB 1521
R37	0690-1521		R:FXD COMP 1500 OHM 10% 1W	01121	GB 1521
R38	0690-2211		R:FXD COMP 220 OHM 10% 1W	01121	GB 2211
R39	0690-6811	1	R:FXD COMP 680 OHM 10% 1W	01121	GB 6811
R40	0690-4741	1	R:FXD COMP 470K OHM 10% 1W	01121	GB 4741
R41	0690-2741	2	R:FXD COMP 270K OHM 10% 1W	01121	GB 2741

Table 5-2. Replaceable Parts

Reference Designation	HP Part Number	Qty	Description	Mfr Code	Mfr Part Number
R42	0690-2731		R:FXD COMP 27K OHM 10% 1W	01121	GB 2731
R43	0690-2741		R:FXD COMP 270K OHM 10% 1W	01121	GB 2741
R44	0690-1041		R:FXD COMP 100K OHM 10% 1W	01121	GB 1041
R45	2100-0084	1	R:VAR COMP 50K OHM 20% LIN 1/3W	28480	2100-0084
R46	0690-8231	1	R:FXD COMP 82K OHM 10% 1W	01121	GB 8231
R47	0816-0013	1	R:FXD WW 15K OHM 10% 10W	28480	0816-0013
R48	0690-1031	1	R:FXD COMP 10K OHM 10% 1W	01121	GB 1031
R49	0690-3301	1	R:FXD COMP 33 OHM 10% 1W	01121	GB 3301
R50	0690-3341	2	R:FXD COMP 330K OHM 10% 1W	01121	GB 3341
R51	0690-3341		R:FXD COMP 330K OHM 10% 1W	01121	GB 3341
R52	0690-3941	1	R:FXD COMP 390K OHM 10% 1W	01121	GB 3941
S1	3101-0001	1	SWITCH:TOGGLE SPST	04009	80994-HB
S2	3101-0005	1	SWITCH:TOG DPDT JAN #ST22N	04009	95691
S3	3100-0114	1	SWITCH-ROTARY 1 SECT 3 POS	28480	3100-0114
S4	3100-0113	1	SWITCH-LEVER 3 POS 2 POLE	28480	3100-0113
S5	415B-19A	1	RANGE SWITCH ASSEMBLY	28480	415B-19A
S5			INCLUDES C4,5, R4-R8, R11, R12, R18		
T1	9100-0059	1	TRANSFORMER:POWER	28480	9100-0059
V1	1932-0030	2	ELECTRON TUBE:12AX7	02735	12AX7
V2	1932-0030		ELECTRON TUBE:12AX7	02735	12AX7
V3	1932-0022	1	ELECTRON TUBE:DUAL TRIODE 6DJ8	73445	6DJ8
V4	1930-0014	1	ELECTRON TUBE:6AX5-GT	02735	6AX5-GT
V5	1923-0020	1	ELECTRON TUBE: 6AU5GT BEAM PENTODE	86684	JEDEC BASE B6 60
V6	1923-0028	1	ELECTRON TUBE: 6CB6A PENTODE	86684	6CB6A
V7	1940-0007	1	ELECTRON TUBE:OB2	02735	OB2
W1	8120-1348	1	CABLE ASSY:POWER, DETACHABLE	70903	KHS-7041
	415B-42A	1	FILTER ASSY:1000-CYCLE	28480	415B-42A
	415B-42B	1	FILTER:SPECIAL FREQUENCY SPECIFY THE PARTICULAR FREQUENCY DESIRED BETWEEN 315 AND 700 CPS BUT AVOID MULTIPLIES OF 60 CPS BY AT LEAST 15 CPS.	28480	415B-42B
	415B-42C	1	FILTER:SPECIAL FREQUENCY SPECIFY THE PARTICULAR FREQUENCY DESIRED BETWEEN 700 AND 2000 CPS BUT AVOID MULTIPLES OF 60 CPS BY AT LEAST 15 CPS	28480	415B-42C
			MISCELLANEOUS		
	415B-16E	1	CABLE:EXTERNAL, RECORDER	28480	415B-16E
	1400-0084	1	FUSEHOLDER:EXTRACTOR POST TYPE	75915	342014
	0370-0023	1	KNOB :3/4 IN	28480	0370-0023
	0370-0046	1	KNOB:BLK LEVER SWITCH	28480	0370-0046
	0370-0033	1	KNOB:SKIRTED BLK 1.0" DIA	28480	0370-0033
	0370-0035	1	KNOB:SKIRTED BAR 1" DIA	28480	0370-0035
	1450-0410	1	LENS:WHITE CAP (LINE POWER)	72765	25-102WHITE

See introduction to this section for ordering information

Table 5-3. Code List of Manufacturers

MFR NO.	MANUFACTURER NAME	ADDRESS	ZIP CODE
01121	ALLEN BRADLEY CO.	MILWAUKEE, WIS.	53204
02660	AMPHENOL CORP.	BROADVIEW, ILL.	60153
02735	RCA SOLID STATE & RECEIVING TUBE DIV.	SOMERVILLE, N.J.	08876
04009	ARROW, HART & HEGEMAN ELECT. CO.	HARTFORD, CONN.	06106
07263	FAIRCHILD CAMERA & INST. CORP. SEMICONDUCTOR DIV.	MOUNTAIN VIEW, CALIF.	94040
08806	G.E. CO. MINIATURE LAMP DEPT.	CLEVELAND, OHIO	44112
28480	HEWLETT-PACKARD COMPANY	PALO ALTO, CALIF.	94304
56289	SPRAGUE ELECTRIC CO.	N. ADAMS, MASS.	01247
65092	WESTON INSTRUMENT INC. WESTERN INST. DIV.	NEWARK, N.J.	07114
70903	BELDEN CORP.	CHICAGO, ILL.	60644
71400	BUSSMANN MFG. DIV. MC GRAW-EDISON CO.	ST. LOUIS, MO.	63017
71471	AEROVOX CORP. CINEMA PLANT	BURBANK, CALIF.	91503
72765	DRAKE MFG. CO.	HARWOOD HEIGHTS, ILL.	60656
73445	AMPEREX ELECT. CORP.	HICKSVILLE LONG IS. N.Y.	11801
75915	LITTELFUSE INC.	DES PLAINES, ILL.	60016
82389	SWITCHCRAFT INC.	CHICAGO, ILL.	60630
86684	RCA ELECTRONIC COMPONENTS	HARRISON, N.J.	07029
93332	SYLVANIA ELECTRIC PROD. INC. SEMICONDUCTOR DIV.	WOBURN, MASS.	01801

APPENDIX I

MANUAL CHANGES

Serial Prefix or Number	Make Manual Changes
23 thru 47	I, H, G, F, E, D, C, B, A
48 thru 97	I, H, G, F, E, D, C, B
98 thru 297	I, H, G, F, E, D, C
298 thru 4182	I, H, G, F, E, D
4183 thru 5582	I, H, G, F, E

Serial Prefix or Number	Make Manual Changes
409-06583 thru 409-07032	I, H, G, F
006-, 007-	I, H, G, F
137-	I, H, G
850-	I, H
970-	I

CHANGE A

Section V, Page 3,
Change T2 to HP Part No. 912-47.

CHANGE B

Section V, Page 2,
Change C10 to C: FXD ELECT 50 UF HP Part No. 0180-0029, and reconnect C10 as follows:
Connect positive (+) terminal to anode of CR1 and negative (—) terminal to cathode of CR2.
Change R10 to R: FXD 1500 OHM 1% 5W HP Part No. 0811-0005.
Change R14 to R: FXD 1500 OHM 10% 1W HP Part No. 0690-1521.

Section V, Page 3,
Change R23 to R: FXD 39K OHM 10% 1W HP Part No. 0690-3931.
Delete R29, R50, and R51.

CHANGE C

Section IV, Page 8,
Reconnect capacitor C3C from across R14 to across R10.

Section V, Page 3,
Change R21 and R25 to R: FXD 2200 OHM 10% 1W.
Change R50 and R51 to R: FXD 680K OHM 10% 1W.

CHANGE D

Section V, Page 3,
Change R25 to R: FXD 1500 OHM 10% 1W HP Part No. 0690-1521.
Change R31 to R: FXD 10K OHM 10% 1W HP Part No. 0690-1031.
Change R32 to R: FXD 220 OHM 10% 1W HP Part No. 0690-2211.
Delete R52.

CHANGE E

Section V, Page 2,
Change P1 to Part No. 8120-0015.

CHANGE F

Section V, Page 2,
Change C2 to C: FXD 500 PF 15 VDCW HP Part No. 0180-0001.

CHANGE G

Section IV, Page 8,
Delete CR3, CR4, CR5 and CR6 and section of S2 to which they connect.

CHANGE G (cont'd)

Section V, Page 2,
Delete CR3, CR4, CR5, and CR6.
Change R1 to R: FXD 160 OHM 5% 1W HP Part No. 0689-1615.
Change R2 to R: FXD 510 OHM 5% 1W HP Part No. 0689-5115.

Section V, Page 3,
Change S2 to SWITCH: SPST HP Part No. 3101-0001.

CHANGE H

Section IV, Page 5,
Replace Figure 4-2 in manual with Figure 4-2 in this Appendix.

Section IV, Page 6,
Replace Figure 4-3 in manual with Figure 4-3 in this Appendix.

Section IV, Page 7,
Replace Figure 4-4 in manual with Figure 4-4 in this Appendix.

CHANGE I

Section IV, Page 2,
Replace Figure 4-5 in manual with Figure 4-5 in this Appendix.

Section V, Page 2,
Change F1 to: HP Part No. 2110-0007 FUSE: CARTRIDGE 1 AMP SLOW BLOW (FOR 115V OPERATION).
HP Part No. 2110-0008 FUSE: CARTRIDGE 1/2 AMP SLOW BLOW (FOR 250V OPERATION).
Delete J4 HP Part No. 1251-2357.
Add P1 HP Part No. 8120-0050 CABLE ASSEMBLY: POWER 3-COND 7.5 FT.

Section V, Page 3,
Delete S6 HP Part No. 3101-1234.
Delete W1 HP Part No. 8120-1348.

Section V, Page 4,
Delete HP Part No. 1450-0413.

APPENDIX II
MODEL 415BR RACK-MOUNT INSTRUMENT

DESCRIPTION

The Model 415BR is the same as the Model 415B cabinet-model instrument except that the physical construction is such that the 415BR can be mounted directly in a standard instrument rack. Dimensions of the 415BR are shown in Table 1-1. The 415BR switches are mounted in different positions relative to each other than on the Model 415B.

OPERATION

The operating procedure, theory of operation, and schematic diagrams are the same for the 415BR as for the 415B.

HEWLETT · PACKARD

ELECTRONIC INSTRUMENTATION SALES AND SERVICE

UNITED STATES, CENTRAL AND SOUTH AMERICA, CANADA

UNITED STATES

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TWX: 810-726-2204

ARIZONA
2336 E. Magnolia St.
Phoenix 85034
Tel: (602) 252-5061
TWX: 910-951-1330

5737 East Broadway
Tucson 85716
Tel: (602) 298-2313
TWX: 910-952-1162

CALIFORNIA
1430 East Orangethorpe Ave.
Fullerton 92631
Tel: (714) 870-1000

3939 Lankershim Boulevard
North Hollywood 91604
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TWX: 910-499-2170

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Tel: (415) 327-6500
TWX: 910-373-1280

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Sacramento 95825
Tel: (916) 482-1463
TWX: 910-367-2092

9606 Aero Drive
San Diego 92123
Tel: (714) 279-3200
TWX: 910-335-2000

COLORADO
7965 East Prentice
Englewood 80110
Tel: (303) 771-3455
TWX: 910-935-0705

CONNECTICUT
508 Tolland Street
East Hartford 06108
Tel: (203) 289-9394
TWX: 710-425-3416

111 East Avenue
Norwalk 06851
Tel: (203) 853-1251
TWX: 710-468-3750

FLORIDA
P.O. Box 24210
2806 W. Oakland Park Blvd.
Ft. Lauderdale 33307
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TWX: 510-955-4099

P.O. Box 20007
Herndon Station 32814
621 Commonwealth Avenue
Orlando
Tel: (305) 841-3970
TWX: 810-850-0113

GEORGIA
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450 Interstate North
Atlanta 30328
Tel: (404) 436-6181
TWX: 810-766-4890

ILLINOIS
5500 Howard Street
Skokie 60076
Tel: (312) 677-0400
TWX: 910-223-3613

INDIANA
3839 Meadows Drive
Indianapolis 46205
Tel: (317) 546-4891
TWX: 810-341-3263

LOUISIANA
P.O. Box 856
1942 Williams Boulevard
Kenner 70062
Tel: (504) 721-6201
TWX: 810-955-5524

MARYLAND
6707 Whitestone Road
Baltimore 21207
Tel: (301) 944-5400
TWX: 710-862-9157

P.O. Box 1648
2 Choke Cherry Road
Rockville 20850
Tel: (301) 948-6370
TWX: 710-828-9684

MASSACHUSETTS
32 Hartwell Ave.
Lexington 02173
Tel: (617) 861-8960
TWX: 710-326-6904

MICHIGAN
21840 West Nine Mile Road
Southfield 48075
Tel: (313) 353-9100
TWX: 810-224-4882

MINNESOTA
2459 University Avenue
St. Paul 55114
Tel: (612) 645-9461
TWX: 910-563-3734

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Kansas City 64137
Tel: (816) 763-8000
TWX: 910-771-2087

2812 South Brentwood Blvd.
St. Louis 63144
Tel: (314) 962-5000
TWX: 910-760-1670

NEW JERSEY
W. 120 Century Road
Paramus 07652
Tel: (201) 265-5000
TWX: 710-990-4951

1060 N. Kings Highway
Cherry Hill 08034
Tel: (609) 667-4000
TWX: 710-892-4945

NEW MEXICO
P.O. Box 8366
Station C
6501 Lomas Boulevard N.E.
Albuquerque 87108
Tel: (505) 265-3713
TWX: 910-989-1665

156 Wyatt Drive
Las Cruces 88001
Tel: (505) 526-2485
TWX: 910-983-0550

NEW YORK
1702 Central Avenue
Albany 12205
Tel: (518) 869-8462
TWX: 710-441-8270

1219 Campville Road
Endicott 13760
Tel: (607) 754-0050
TWX: 510-252-0890

82 Washington Street
Poughkeepsie 12601
Tel: (914) 454-7330
TWX: 510-248-0012

39 Saginaw Drive
Rochester 14623
Tel: (716) 473-9500
TWX: 510-253-5981

5858 East Molloy Road
Syracuse 13211
Tel: (315) 454-2486
TWX: 710-541-0482

1 Crossways Park West
Woodbury 11797
Tel: (516) 921-0300
TWX: 510-223-0811

NORTH CAROLINA
P.O. Box 5188
1923 North Main Street
High Point 27262
Tel: (919) 885-8101
TWX: 510-926-1516

OHIO
25575 Center Ridge Road
Cleveland 44145
Tel: (216) 835-0300
TWX: 810-427-9129

3460 South Dixie Drive
Dayton 45439
Tel: (513) 298-0351
TWX: 810-459-1925

1120 Morse Road
Columbus 43229
Tel: (614) 846-1300

OKLAHOMA
2919 United Founders Boulevard
Oklahoma City 73112
Tel: (405) 848-2801
TWX: 910-830-6862

OREGON
Westhills Mall, Suite 158
4475 S.W. Scholls Ferry Road
Portland 97225
Tel: (503) 292-9171
TWX: 910-464-6103

PENNSYLVANIA
2500 Moss Side Boulevard
Monroeville 15146
Tel: (412) 271-0724
TWX: 710-797-3650

1021 8th Avenue
King of Prussia Industrial Park
King of Prussia 19406
Tel: (215) 265-7000
TWX: 510-660-2670

RHODE ISLAND
873 Waterman Ave.
East Providence 02914
Tel: (401) 434-5535
TWX: 710-381-7573

TEXAS
P.O. Box 1270
201 E. Arapaho Rd.
Richardson 75080
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